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Monograph

ENVIRONMENTAL PROTECTION
TRANSPORT AND LOGISTICS
PRODUCTION ENGINEERING

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Sławomir Kowalski

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Contents

Introduction

We present a monograph containing selected articles for the papers presented at the International Multidisciplinary Scientific Conference MMKN'23. The conference was held on 29-30 May 2023 in Eco Active Resort Pieniny Hotel in Czorsztyn, 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

Analysis of the development of renewable energy sources in Poland 2017-2021

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Abstract: Renewable energy sources are now an alternative because of rising energy prices in Poland. At the same time, they have become one of the main topics of discussion around the world over the course of 2017-2021. In Poland, they are becoming an alternative to fossil fuels and RES policies are being implemented more and more efficiently both at the national economy, industry and household level. The analysis of the development of renewable energy sources in Poland has shown that they still account for a small but increasing share of the national economy, with wind power being one of the most popular, environmentally friendly ways of generating electricity. In conducting the research, a method involving document research was used, from which it was deduced that in Poland, coal was among the most popular sources of energy generation. Considering renewable energy sources, the production of energy using wind turbines, solar panels, photovoltaics, biomass has increased over the years thanks to investments in our country. Renewable energy sources are an alternative to fossil fuels, but the country's investment in this direction is needed to increase the number of RES installations in the country. This would reduce CO_2 emissions into the atmosphere in an environmentally friendly way and reduce existing energy prices.
Key words: Renewable energy sources, climate and environment, green energy, energy transition.

1. Introduction

According to Directive 2009/28/EC, we can define renewable energy sources (RES) as energy from non-fossil sources, i.e. energy from wind, solar radiation, geothermal sources, but also biogas from landfills, sewage sludge. When addressing the issue of analysing the development of renewable energy sources in Poland, one can look at the question of what part of today's economy they represent. The impact from the use of RES can be considered on three levels: continued sustainability, protection of the environment and natural resources, and the timeless, inexhaustible nature of the raw material used, sourced at minimal operating costs (Gołąbeska, 2010). At the beginning of the 19th century, coal was the main source of energy and surpassed the contribution of other raw materials, such as biomass, in the energy generation process. In the 20th century, international law has undergone a significant metamorphosis, generating many regulations that speak to the sustainable development of the Earth (Burchart-Dziubińska, Rzeńca, Drzazga, 2014), thus creating many problems whose solution is only possible through the consensus of the international community and solidarity and their care in obtaining RES. This includes the protection of human rights, the enjoyment of common goods or the emergence of threats to human health and the natural environment (Bukowski, 2009). The current state of the economy allows renewables to contribute to the overall energy production, but they do not replace fossil fuels but only increase the overall amount of energy produced. It is now often assumed that renewables will account for an increasing share of the world's energy supply, but it is misleading to identify an upward trend and the share of renewable energy as a source of energy acquisition which may consequently inhibit the implementation of RES policies that are primarily aimed at reducing fossil fuel consumption (York, Bell, 2019). In Poland, the introduction of renewable energy sources in recent years has been associated with the inconsistent application of government policy towards the development of green energy solutions. One example is the document on Poland's Energy Policy, according to which a coherent and comprehensive concept for the development of Poland's energy sector, including renewable energy sources, should be in place by 2030, but the document has not been updated since 2009. Despite the obligation of the Minister of Energy (formerly the Minister of Economy) to submit, every year, information on the implementation of the Polish Energy Policy until 2030, the last information adopted by the Council of Ministers concerned the year 2012. Regulatory volatility and uncertainty, as well as complex rules requiring interpretation, have not served to increase investor confidence translating into investment growth in the sector (Koebrich, Bowen, Forrester, Tian, 2019). This is worrying in terms of alternative energy generation, the traditional ways of which have so far contributed, along with other factors, to the generation of still high concentrations of PM 10 and PM 2.5 particulate matter in Poland (Bajor, 2017). The variety of possibilities for obtaining energy in an environmentally safe manner should determine more and more extensive and bolder actions in introducing these technologies to the Polish market. In 2015, the trend in the development of renewable energy sources was upward. More than 71% of energy came from water gravity, and projections for 2020 showed that the share of renewable energy in the overall energy mix would exceed 20% (Paska, Pawlak, Surma, 2013). In order to be able to use renewable energy, it is important to bear in mind first and foremost that the ways in which it can be used are determined by a number of factors, the most important of which are technical, economic, market and implementation aspects. Furthermore, it has to be taken into account that each country has a certain specific RES potential, which cannot generally be compared by similar latitude, accessibility to the sea, ocean, number of watercourses or the share of agricultural crops and forests to the total area, and in addition, ways of estimating biomass resources solely on the basis of statistical data or other factors specific to a particular RES source (e.g. wind conditions on the basis of data from meteorological stations) carry the risk of error at local level (municipalities, districts). Errors of this type can lead, in extreme cases, to potential investors abandoning their investments, as they become generally available in the Low Carbon Economy Programmes (so-called PGNs) adopted for implementation by local authorities and may underestimate the estimated benefit potential (Mirowski, 2017).

2. Research problem and method

The article uses material showing the contribution of renewable energy carriers to the development of the environment, climate and, above all, green energy in Poland. An important aspect is Poland's membership of the European Union, which imposes an obligation to increase the use of RES in the energy mix to at least 32% by 2030 (Nowakowska--Krystman, Sośnicki, Burchert-Perlińska, 2022). Additional measures taken by the Polish state are the decarbonisation of the energy sector, where the key and primary objective is the transformation of the electricity generation sector, so far using 45% RES (Poland 2022, 2022). The ability to both sustained economic activity and maintain a stable and non-impoverished environment are considered elementary societal needs (Blaszczuk, Sawicki, Michalski, Prandecki, 2015).

The performance of the analysis over the period 2017-2021, was carried out using the method of examining documents in the form of reports and statistical data published by the Central Statistical Office. The statistics presented – were analysed in detail in the topic of the development of renewable energy sources in Poland between 2017 and 2021. Subsequently, the contribution of each issue was summarised, in the form of a tabular entry, calculations, and also in comparative graphs in the available Microsoft Excel programme. Between 2017 and 2021, the use of renewable energy sources in energy production increased significantly from 14.38% to 21.12% (Berent-Kowalska, Jurgaś, Kacprowska, Moskal, Kapica, 2022), which is effectively illustrated by a juxtaposition with the analysis of the performance of individual shares of renewable energy in its development. Table 1 details the share of individual renewable energy carriers in the generation of energy from renewable sources in Poland between 2017 and 2021.

Table 1

The share of individual renewable energy carriers in the generation of energy from renewable sources in Poland between 2017 and 2021

Energy carrier type	**2017**	**2018**	**2019**	**2020**	**2021**
	%				
Solid biofuels	66.76	76.13	73.41	71.61	69.35
Solar energy	0.74	0.69	1.08	1.99	3.31
Water energy	2.38	1.40	1.37	1.46	1.57
Wind energy	13.89	9.11	10.59	10.85	10.90
Biogas	3.04	2.39	2.43	2.58	2.49
Liquid biofuels	9.94	7.50	7.99	7.79	8.1
Geothermal energy	0.24	0.20	0.20	0.20	0.22
Municipal waste	1.00	0.81	0.83	1.15	1.16
Heat pumps	1.99	1.77	2.08	2.38	2.89

Source: https://stat.gov.pl/ (access: 18.03.2023).

Analysing the above overview, it can easily be concluded that solid biofuels as a renewable energy carrier have a dominant position in energy generation and use. This shows conformity with the assumptions made earlier that in the transport sector the contribution of advanced biofuels and biogas as a share of final energy consumption will be on an upward trend and is expected to be at least: 0.2% in 2022, 1% in 2025 and 3.5% in 2030 (Polish Chamber of Biofuels, 2020). In 2021, it was noted that the share of biofuels is predominant, as it amounted to 69.35%. Contributing to the continued growth in biofuel consumption is the fact that biofuels are types of renewable energy derived from organic matter (living matter or biomaterials) and, in fact, their energy content comes from biomass, which can be found in the form of liquids (bioethanol and biodiesel), solids (dry plant material) and gases (biogas). Additionally, biofuels such as biodiesel and bioethanol can be used in motor vehicles due to their high energy value and compatibility with fuel infrastructure (Abyaz, Najafi, Afra, 2016). In 2021, it was noted that solar energy also achieved the highest growth of 516%, heat pumps of 102%, municipal waste of 60.8%, and geothermal energy of 26% compared to 2017, a response to rising and volatile energy prices, with some investors choosing to build renewable assets such as solar, wind, hydrogen and energy storage in their own locations which reduces cost risks (Nowakowska-Krystman, Sośnicki, Burchert-Perlińska, 2022). Table 2 shows the distribution of the amount of electricity produced from RES for the different energy carriers.

Table 2
Electricity production from renewable energy carriers in Poland 2017-2021

Energy source	**2017**	**2018**	**2019**	**2020**	**2021**
	GWh				
Total	24,122.1	21,617.2	25,458.8	28,226.6	30,568.5
Water	2,559.6	1,970.0	1,958.4	2,118.3	2,339.2
power plants with a generating capacity < 1 MW	366.6	12,798.8	312.6	432.4	328.3
power plants with a generating capacity from 1 to 10 MW	688.0	528.5	538.2	526.3	632.9
power plants with a generating capacity > 10 MW	1,505.1	1,142.5	1,107.6	1,168.6	1,378.0
Wind	14,909.0	12,798.8	15,106.8	15,800.0	16,233.5
Solid biofuels	5,308.6	5,333.2	6,441.2	6,932.8	6,398.4
Including co-firing	1,810.8	1,461.0	1,800.3	1,945.4	2,040.0
Municipal waste	80.7	85.0	104.8	181.8	353.8
Biogas	1,096.4	1,127.6	1,135.0	1,233.9	1,307.3
biogas from landfills	199.6	169.6	178.0	183.5	204.7
biogas from waste water treatment plants	340.1	336.5	350.8	373.3	367.8
Other biogas	556.7	621.6	606.2	677.0	734.9
Biofluids	2.4	2.0	2.0	1.9	1.7
Photovoltaic cells	165.5	300.5	710.7	1,957.9	3,934.4

Source: https://stat.gov.pl/ (access: 18.03.2023).

Over the period 2017-2021, electricity generation using photovoltaics achieved a growth of 2,277.8%. It uses fully natural conversion processes: photovoltaic, passive or active photothermal and photochemical conversion, during which electricity is generated (Gołąbeska, Harasimowicz, 2023). On the other hand, the use of biogas and solid biofuels in the production of electricity has become increasingly popular, which in local energy systems based on the use of waste biomass from forests, orchards, parks, agriculture, wood industry, but also in the form of sewage sludge, constitutes an element of renewable energy sources (RES) (Ciuła, Kowalski, Wiewiórska, 2023). A fully renewable energy source in this configuration is biogas extracted from landfill sites, sewage treatment plants, but primarily processed in combined heat and power (CHP) systems, thus creating the potential for both electricity and heat generation. In addition, it is encouraging that there is a continuing desire to optimise and utilise heat from renewable sources (Ciuła, Generowicz, Gaska, Gronba-Chyła, 2022). Performing the necessary calculations, it was analysed that the use of biogas increased by 19.2% and the use of solid biofuels by 20.5% comparing 2021 with

2017. Small and large wind power plants also achieved dynamic growth, as there was an increase from 14 909 GWh to 16 233.5 GWh. It is assumed that in 2040, more than half of the installed capacity will be zero-emission sources, and a special role in this process in Poland is to be played by the implementation of offshore wind energy into the Polish electricity system (https://www.gov.pl). In addition, wind energy within other countries reaches an energy potential of 1.3% and widely used especially in areas that are able to exploit this energy source (Azadi, NezamSarmadi, Shirvani, 2017). Municipal waste, which is the sum total of the waste produced by the so-called domestic sector, commerce and public services, and is collected by specialised sanitation facilities at landfills, is difficult to assess as a valuable RES energy carrier, as it is aggregated through statistical data capturing all combustible products contained in municipal waste (Norwisz, Musielak, Boryczko, 2006). Based on data from the Central Statistical Office, they have gained an incremental share of energy production over the last five years, as 80.7 GWh were recorded as being used in electricity production in 2017 and 273.1 GWh more in 2021. Table 3 shows the share of renewable energy carriers in heat production for Poland between 2017 and 2021.

Table 3
Heat production from renewable energy carriers in 2017-2021

Energy carrier	**2017**	**2018**	**2019**	**2020**	**2021**
	TJ				
Total	13,047.9	14,809.1	17,644.6	21,204.9	23,511.4
Solid biofuels	11,691.3	13,401.3	15,901.9	18,655.4	20,942.8
Municipal waste	457.0	476.6	730.7	1611.9	1598.9
Biogas	890.9	922.5	1,004.2	927.6	959.3
Biogas from landfills	59.5	31.4	35.5	47.7	38.6
Biogas from waste water treatment plants	130.7	106.2	105.6	97.0	148.7
Other biogas	700.7	784.9	863.2	782.9	772.0
Biofluids	3.2	3.4	4.6	5.5	5.0
Heat pumps	5.5	5.3	3.1	4.5	5.3

Source: https://stat.gov.pl/ (access: 18.03.2023).

An overall increase in heat generation was recorded between 2017 and 2021, thanks to the share of renewable energy carriers. Heat production has increased over the years to 23,511.4 TJ. The share of solid biofuels has steadily increased year on year, with 11,691.3 TJ in 2017 and 20,942.8 TJ in 2021. At the same time, the development of energy production using biogas and municipal waste has occurred. In 2017, renewable heat production for biogas was recorded at 890.9TJ and it will increase to 959.3 TJ in the 2021. On the other hand, the use of renewable energy carriers in the form of bioliquids and heat pumps is still becoming popular among the population, so there is a gradual increase.

Between 2017 and 2021, the share of renewable energy in gross final energy consumption gradually increased. The rapid growth in demand for renewable energy has seen the use of this method of energy generation in heating and cooling increase from 14.78% to 21.03% in four years. In 2021, it was also observed that the value of the share of energy from RES in the electricity sector intensified by 4.09%, compared to 2017. During the period under review, there was a systematic intensity and increase in the importance of renewable energy in transport – in 2021 it was 1.43% higher compared to 2017.

Table 4
The share of renewable energy in gross final energy consumption 2017-2021

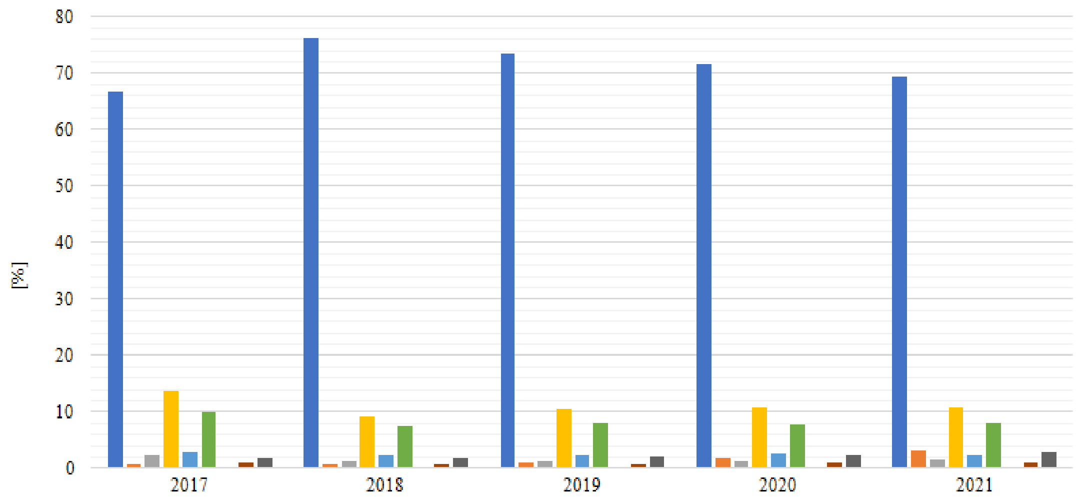
Areas of RES use	**2017**	**2018**	**2019**	**2020**	**2021**
	[%]				
The share of RES energy in heating and cooling	14.78	21.47	22.00	22.14	21.03
The share of energy from RES in the electricity sector	13.08	13.03	14.36	16.24	17.17
The share of RES energy in transport	4.23	5.72	6.20	6.58	5.66
The share of energy from renewable sources in gross final energy consumption	11.06	14.94	15.38	16.10	15.62

Source: https://stat.gov.pl/ (access: 30.03.2023).

3. Results and discussion

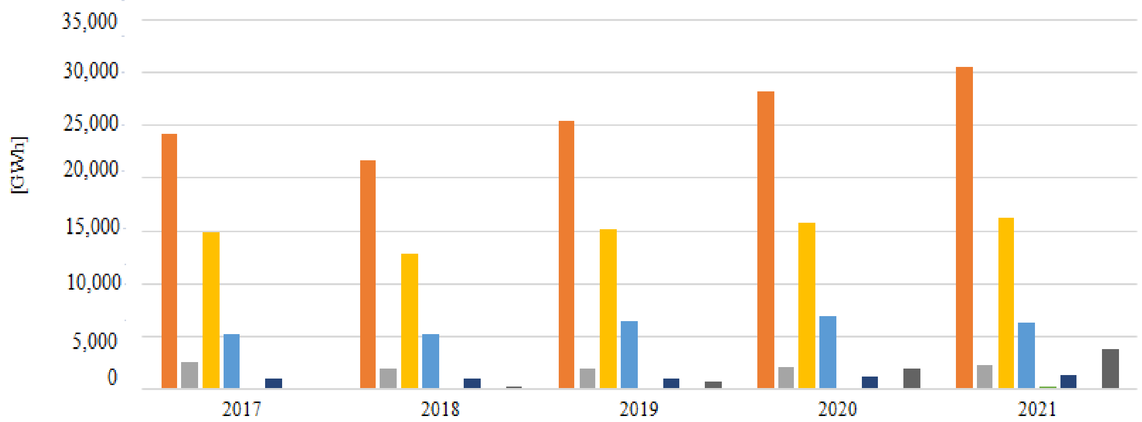
Dynamic industrial growth and energy demand, over the period 2017-2021, has resulted in an intensification of the use of renewable energy sources by the public and its generators. The main reason for these changes is the growing problems associated with the depletion of fossil fuel resources and their adverse effects on the health and life of society and the environment. Renewable energy carriers in energy generation are of growing interest to the public in Poland. In addition, the use of heating systems that can significantly reduce energy consumption has a major impact on the decarbonisation of energy. The best effects of energy efficiency measures for residential buildings in particular can be achieved simultaneously by sealing the building through improved thermal insulation and installing more efficient, more effective heating equipment (Gołąbeska, 2019).

When analysing the results obtained for the share of individual renewable energy carriers in the generation of energy from renewable sources in Poland in 2017-2021, it should be noted that the development of green energy is growing dynamically, having a positive impact on the climate and the environment. Figure 1 shows in detail the changes in the share of individual renewable energy carriers in the generation of renewable energy in Poland. On the other hand, Figure 2 summarises the changes in electricity production from renewable energy carriers in Poland and Figure 3 the changes in heat production from renewable energy carriers between 2017 and 2021. Figure 4 shows the share of renewable energy in gross final energy consumption from 2017 to 2021 to show the progress of environmental protection and the essence of the use of renewable energy sources. The purpose of the tabulation and comparison charts in Microsoft Excel is to show the continuous development of renewable energy sources over the years and the essence of using an environmentally friendly energy conversion method that renews itself in a short period of time.



	2017	2018	2019	2020	2021
Solid biofuels	66.76	76.13	73.41	71.61	69.35
Solar energy	0.74	0.69	1.08	1.99	3.31
Water energy	2.38	1.4	1.37	1.46	1.57
Wind energy	13.89	9.11	10.59	10.85	10.9
Biogas	3.04	2.39	2.43	2.58	2.49
Liquid biofuels	9.94	7.5	7.99	7.79	8.1
Geothermal energy	0.24	0.2	0.2	0.2	0.22
Municipal waste	1	0.81	0.83	1.15	1.16
Heat pumps	1.99	1.77	2.08	2.38	2.89

Figure 1. The share of individual renewable energy carriers in the generation of energy from renewable sources in Poland in 2017-2021.
Source: own study based on: https://stat.gov.pl/ (access: 30.03.2023).



	2017	2018	2019	2020	2021
Total	24,122.10	21,617.20	25,458.80	28,226.60	30,568.50
Water	2,559.60	1,970.00	1,958.40	2,118.30	2,339.20
Wind	14,909.00	12,798.80	15,106.80	15,800.00	16,233.50
Solid biofuels	5,308.60	5,333.20	6,441.20	6,932.80	6,398.40
Municipal waste	80.70	85.00	104.80	181.80	353.80
Biogas	1,096.40	1,127.60	1,135.00	1,233.90	1,307.30
Biofluids	2.40	2.00	2.00	1.90	1.70
Photovoltaic cells	165.50	300.50	710.70	1,957.90	3,934.40

Figure 2. Electricity production from renewable energy carriers in Poland in 2017-2021.
Source: own study based on: https://stat.gov.pl/ (access: 30.03.2023).

When analysing the share of the various energy carriers, it should be noted that the development of renewable sources in energy conversion was on the rise between 2017 and 2021, with solid biofuels being the most popular for obtaining energy. In 2017, their share was 66.76%, in 2018 there was a sudden increase to 76.13%, consecutively in 2019 their share was more than 73% which was still associated with a high percentage, relative to 2020-2021. Similarly, solar energy is of dynamic interest to the public in obtaining energy, thanks to this renewable energy carrier. In 2017, their share was 0.74%, where it gradually increased over the following years. Only in 2018 was there a decrease in their use to 0.69%. However, over the following years, in 2021, a significant increase in energy generation by 14,854 TJ, ie. 516%, was achieved. It is also worth mentioning heat pumps, which in 2021 recorded their largest share of energy received until 2017. In 2017, heat pumps contributed 1.99%, with an increase of 7,812 TJ, ie. 102%, recorded over the following years.

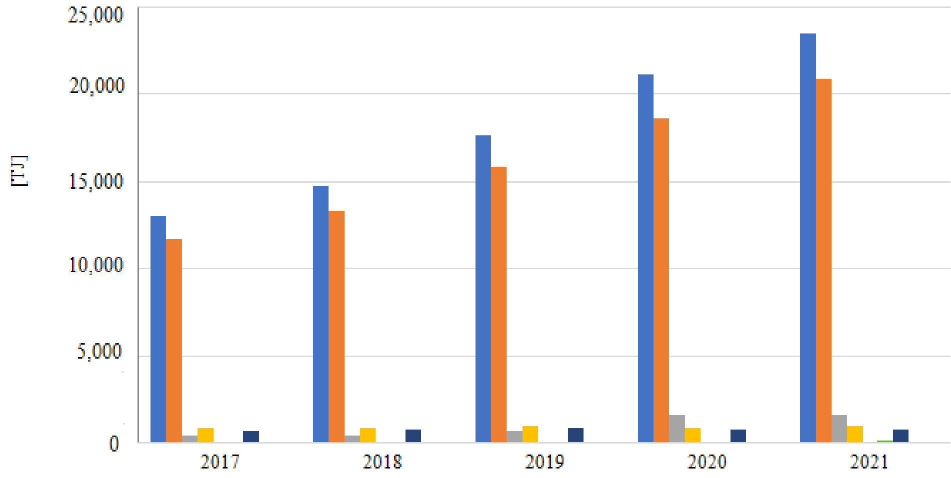
Figure 2 shows the evolution of electricity generation from renewable energy carriers in Poland between 2017 and 2021

A detailed analysis of the changes in the production of electricity from renewable energy carriers in Poland made it possible to conclude that between 2017 and 2021, their share increased by 6,446.4 GWh, 27% more than in 2017. Electricity generation using photovoltaics enjoyed a high share, as a growth of 2,277.8% was achieved between 2017 and 2021. Biogas also achieved its positive percentage in 2017, amounting to 1,096.4 GWh, 2018 saw an increase to 1,127.6 GWh, 2019 saw an increase of 7.4 GWh, as did 2020 by 98.9 GWh on the previous year, while the highlight of its growth was the period of 2021, as there was an increase in electricity production of 19.2% more than in 2017. Municipal waste, like other renewable energy carriers, received a boost, as 80.7 GWh were recorded as being used in electricity generation in 2017 and 273.1 GWh more in 2021. Given the emphasis on minimising waste and landfill, there is an increasing emphasis on waste management, including through recycling, prevention, but also use for energy recovery (Cenian, Pietrzykowski, 2018). It is reasonable to obtain biogas from waste and process it in cogeneration systems, thereby minimising environmental pollution while producing energy in a low-emission way that minimises pollutants emitted into the air and soil (Weiland, 2000).

With the help of the statistical material obtained from the website of the Central Statistical Office, the production of heat from renewable energy carriers for the period 2017-2021 was collated, the results are shown in Figure 3.

The share of renewable energy carriers in heat production is found to have recorded an overall increase between 2017 and 2021 to 23,511.4 TJ. A key contributor to heat production was the use of solid biofuels. In 2017, 11,691.3 TJ was recorded, in 2018 the result was 13,401.3 TJ and in 2019 15,901.9 TJ, in 2020 it was recorded, an increase of 2,753.5 TJ compared to the previous year, while in 2021 the share of biofuels in heat production increased to 20,942.8 TJ. At the same time, the development of energy production using biogas and municipal waste has occurred. In 2017, renewable heat production for biogas was recorded at 890.9TJ and it will increase to 959.3 TJ in the 2021.

Figure 4 shows the change in the share of renewable energy in gross final energy consumption from 2017 to 2021.



	2017	2018	2019	2020	2021
Total	13,047.90	14,809.10	17,644.60	21,204.90	23,511.40
Solid biofuels	11,691.30	13,401.30	15,901.90	18,655.40	20,942.80
Municipal waste	457.00	476.60	730.70	1,611.90	1,598.90
Biogas	890.90	922.50	1,004.20	927.60	959.30
Biogas from landfills	59.50	31.40	35.50	47.70	38.60
Biogas from waste water treatment plants	130.70	106.20	105.60	97.00	148.70
Other biogas	700.70	784.90	863.20	782.90	772.00
Biofluids	3.20	3.40	4.60	5.50	5.00
Heat pumps	5.50	5.30	3.10	4.50	5.30

Figure 3. Heat production from renewable energy carriers in 2017-2021.
Source: own study based on: https://stat.gov.pl/ (access: 30.03.2023).

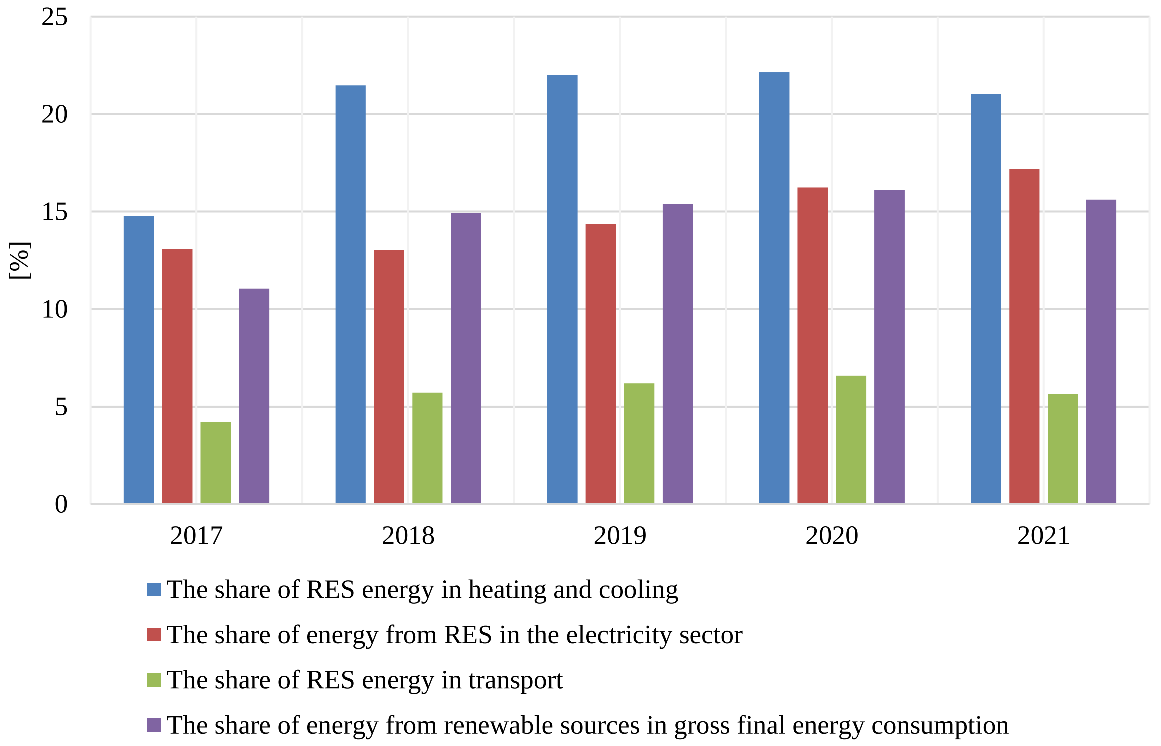


Figure 4. The share of renewable energy in gross final energy consumption in 2017-2021.
Source: own study based on: https://stat.gov.pl/ (access: 30.03.2023).

An overall analysis of the change in the share of renewable energy sources in gross final energy consumption between 2017 and 2021 shows that their share increased by 4.56% over the period in question, and the popularity of renewable energy sources continues to grow and could have a significant impact on their use in total energy generation in the future. The share of RES energy in heating and cooling in gross national energy consumption in the period under review was the highest – compared to transport or electricity. In 2017, the use of RES energy was recorded at 14.78%, in 2018 their presence increased to 21.47%. In 2019 and 2022, values of 22% and 22.14% were recorded. By contrast, in 2021, their share of RES energy in heating and cooling was 21.03%. It is crucial that the reduction of air emissions, mainly from the electricity sectors, becomes one of the main goals of caring for the environment with a simultaneous emphasis on a partial transition away from fossil fuels to renewable energy sources, which, through local application, improve a country's energy security and thus reduce the possibility of a blackout. In addition, they can become a certain pillar in terms of protecting the country's critical infrastructure, the purpose of which is to ensure the security of the functioning of the state and its citizens (Basta, Dyrek, Ciuła, 2022).

4. Conclusions

The use of renewable energy sources is becoming increasingly popular worldwide, but also in Poland. The current state of the economy allows renewable energy sources to contribute to the overall energy production, however, they do not replace fossil fuels, but only increase the overall amount of energy produced, in addition, inconsistent application of state policy towards the development of green energy solutions can be observed in our country, which can result in misinformation and discouragement towards RES energy production. This article analyses the development of renewable energy sources in Poland between 2017 and 2021. Documentary research into the production and use of energy from renewable sources in Poland has produced the following results:

- solid biofuels, as a renewable energy carrier, have the dominant position in the acquisition and use of energy, and their quantity amounted 69.35% of alternative fuels in 2021;
- in 2021, it was noted that the biggest increases were: solar energy by 516%, heat pumps by 102%, municipal waste by 60.8%, geothermal energy by 26% compared to 2017;
- over the period 2017-2021, electricity generation using photovoltaics achieved a growth of 2,277.8%;
- an overall increase in heat production was recorded between 2017 and 2021, rising to 23,511.4 TJ thanks to the share of renewable energy carriers;
- the development of energy production, and in particular heat production, took place using biogas and municipal waste, it increased and amounted to 890.9TJ in 2017 and was equal to 959.3 TJ in 2021.

A positive outcome of the analysis is that renewables are increasingly a significant part of the energy mix with traditional fossil fuels, and the increased environmental awareness of the public is contributing to the upward trend in the use of RES as of 2017.

In power generation, the increase is for the period 2017-2021 around 600 GWh, and in district heating around 10,000 TJ. The share of RES in heating and cooling in gross national energy consumption was the highest, compared to transport or electricity, with an average increase of around 7% over the period 2017-2021. The use of energy from renewable sources, fits in with plans to decarbonise the Polish energy sector as part of the energy transition.

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Analysis and selection of installation for thermal processing of municipal waste

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Abstract: Based on the analysis, it was shown that it will be possible to locate the installation to be removed in the Sądecki Subregion. It was assumed that the amount of generated municipal waste will increase with a maximum mass of 105,000 Mg/year. Assumed boiler efficiency is 81% with the amount of municipal waste of 11.9 Mg/h, it will provide an energy yield of 40,827.6 kWh. As a result, the amount of energy generated per year will amount to 357,649,776 kWh. A high share of more than 30% in the mass of mixed high-calorific plastic waste should be considered beneficial.
Key words: thermal treatment of waste, flue gas purification.

1. Introduction

According to the definition of the Act on waste, waste is any substance or object which the holder disposes of, intends to dispose of or is obliged to dispose of. Waste is an inseparable part of human existence. With the development of technology, as well as the passing of years, when the number of inhabitants on the planet grew, the production of waste increased. Due to poor waste management, the ecological situation has deteriorated.

Waste management methods should be selected in accordance with the hierarchy of conduct, i.e. prevention is the most desirable, and as a last resort, neutralization of waste in landfills. The most common methods of waste management include: landfilling, recycling, composting and thermal treatment with energy recovery (Wyrozębska et al., 2018).

There are known technologies that allow the re-use of waste whose further recycling is impossible due to wear and tear, and thanks to the development of waste incineration techniques, one can look optimistically into the future, starting from storage, through combustion processes, to energy recovery to reuse. Currently, the biggest problem is the selection of a location for the construction of a waste incineration plant (Wielgosiński, 2020).

Both the location and the technology of the thermal waste processing plant should meet ecological requirements and social recognition, and also take into account the size of the stream of municipal waste generated in a given area (Nęcka, Szul, 2022).

To meet the emission standards, it is necessary to invest in filtering systems, without which the incineration plant will not be allowed to operate.

It is necessary to filter out as much particulate matter as possible and to minimize the amount of gases produced in the combustion process (Nadziakiewicz et al., 2007).

According to the Regulation of the Minister of Climate of September 24, 2020 on emission standards for certain types of installations, fuel combustion sources, and waste incineration or co-incineration equipment, it is necessary to use a multi-stage flue gas cleaning system, which would include the following elements: dedusting, acid gas removal, nitrogen oxide removal, heavy metal removal and organic compound removal.

The aim of the work was to select the location of the municipal waste incineration plant in the Sądecki Subregion, together with the specification of the technical parameters of the installation.

2. Methodology

Data for analytical purposes were obtained from the Central Statistical Office (www.bdl.pl). The data used was used to determine the number of inhabitants and the amount of waste collected non-selectively and selectively in the Nowy Sącz Subregion: the city of Nowy Sącz, Limanowa, Gorlice and the districts of Nowy Sącz, Limanowa and Gorlice in the years 2017-2021.

Based on the collected data, a trend line was determined. The technical parameters of the installation were also specified, along with the determination of costs, among others using a calculator (www.uigmbh.de).

3. Characteristics of the city of Nowy Sącz

Nowy Sącz is a city with county rights, with an area of 60 km^2, located in the central part of the Nowy Sącz county (Figure 1). The city is located at an altitude of about 281 m above sea level. The average temperature is 8^{o}C, and the hottest month is July with a temperature of 19^{o}C, and the coldest is January with an average temperature of -5^{o}C.

Figure 1. Location of Nowy Sącz against the backdrop of the count.
Source: http://www.gminy.pl (access: 10.05.2023).

4. Selection of the location of the installation for thermal waste treatment

The location of the installation for thermal waste treatment is planned in the southern part of the city of Nowy Sącz. This area is characterized by the location of production plants along with facilities between Węgierska Street and the Dunajec River on a plot near the manufacturer of roof windows FAKRO. The plot of approximately 17.5 ha will be suitable for the location of the incineration plant. Thanks to such a location, it will be possible to use thermal energy not only on its own but also in the economic environment. The nearest residential buildings are located at a distance exceeding 1 km. The spatial development plan for Nowy Sącz does not take into account the creation of compact residential development in this area (Figure 2), but it provides the possibility of locating a building or a service or production hall. This location is outside the areas of natural value (geoserwis.gdos.gov.pl).

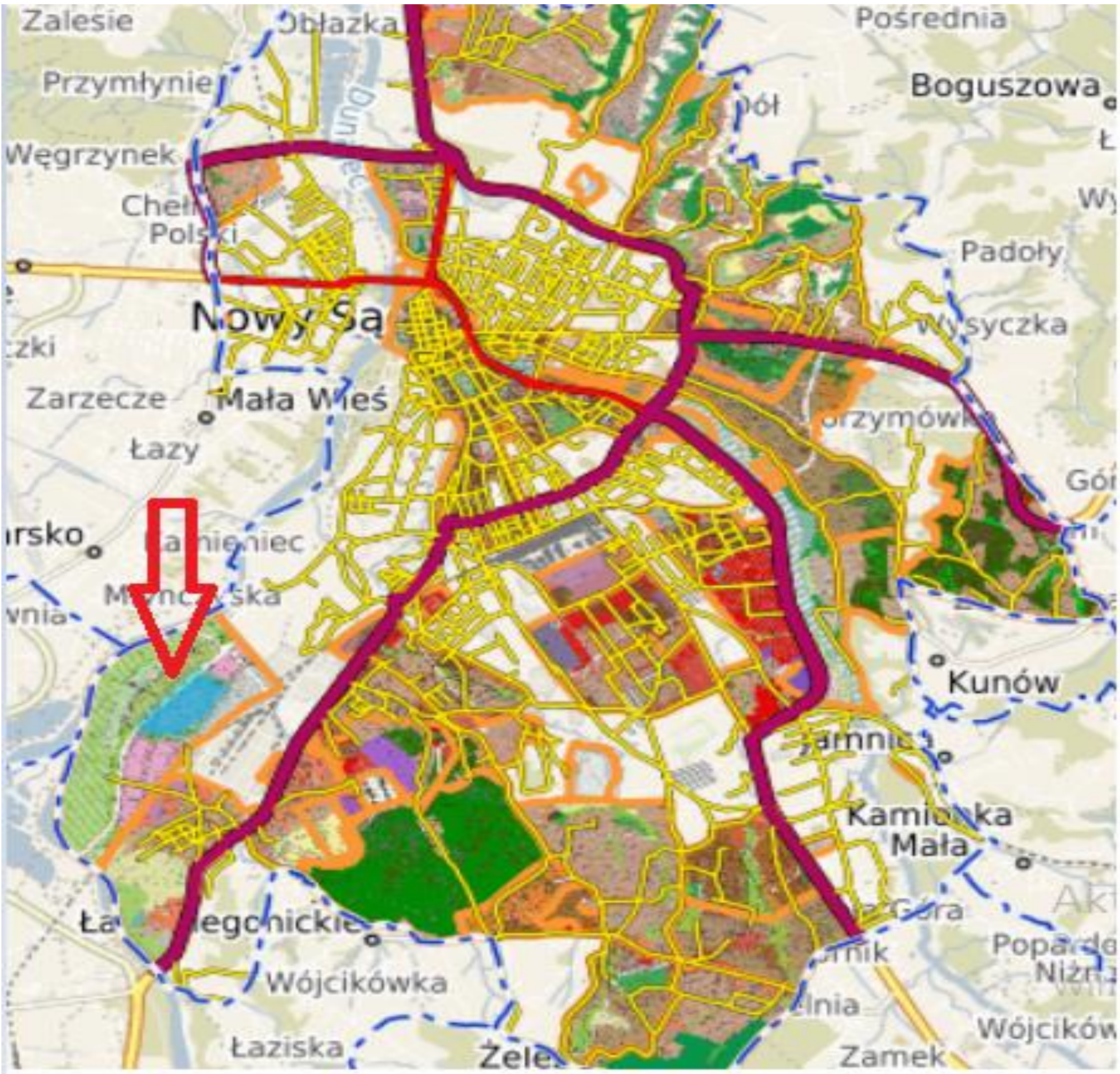

Figure 2. Spatial development plan for the city of Nowy Sącz with a marked plot for the planned location of the waste incineration plant.
Source: https://mnowysacz.e-mapa.net (access: 10.05.2023).

5. Analysis of the results with discussion

In the years 2017-2021, an upward trend in the amount of municipal waste generated was noticeable. The amount of segregated waste in the analyzed period more than doubled, which proves the increased awareness of society in the field of recycling. This indicates an increase in segregated waste by 29,453.93 Mg, and in total municipal waste collected by 9,798.39 Mg. The highest amount of collected municipal waste occurred in 2021 (104,607.65 Mg), and the lowest (91,764.41 Mg) in 2020, with an average of 97,506.472 Mg. In the case of segregation, the highest was recorded in 2021, 53,409.23 Mg, while the lowest was in 2017, 23,955.3 Mg, with an average of 41,550.142 Mg. This indicates that society becomes responsible through social campaigns and segregates waste to be able to reuse it through the recycling process (Malinowski et al., 2009).

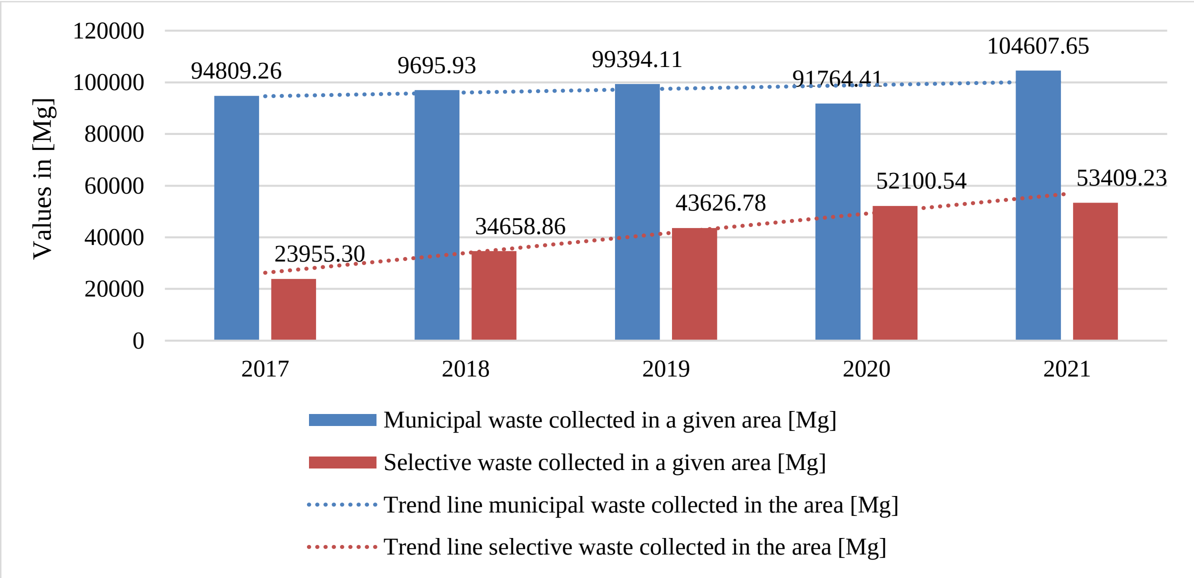

Figure 3. Amount of waste collected in the study area in 2017-2021.
Source: own study based on data from the Central Statistical Office.

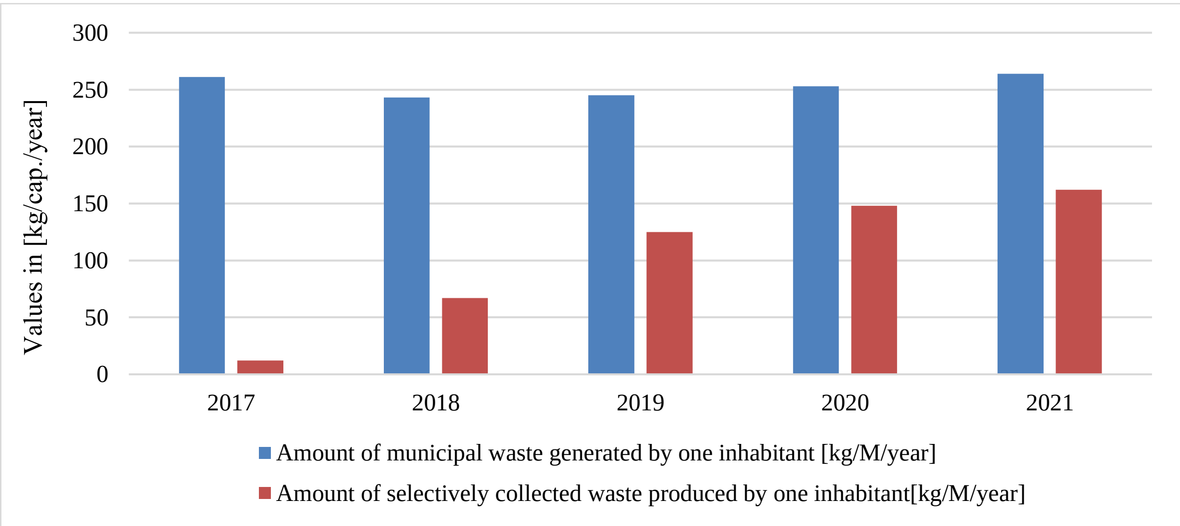

Figure 4. Amount of waste generated per capita in the city of Nowy Sącz.
Source: own study based on data from the Central Statistical Office.

The average amount of waste generated in the analyzed area amounted to 97,506.47 Mg and will affect the parameters of the waste thermal treatment installation, including the production of heat and electricity. Figures 4-9 show the continuing upward trend in the generation of municipal waste in the counties of Nowy Sącz and Limanowa, as well as in the cities of Nowy Sącz and Limanowa. The highest value of the mixed waste accumulation indicator per capita during the years under study was in 2021 in Limanowa and amounted to 350 kg/cap./year. The lowest indicator for the collection of municipal waste per capita, 127 kg/year, occurred in the Limanowa county in 2020. They showed higher values of waste accumulation indicators per capita Przydatek and Ciągło (2020). Sorted waste is collected in much smaller amounts, as evidenced by the fact that the largest amount of this waste was collected in 2021 in Nowy Sącz with a total weight of 162 kg/cap./year, and the least was collected in 2017 when this value was 12 kg/cap./year.

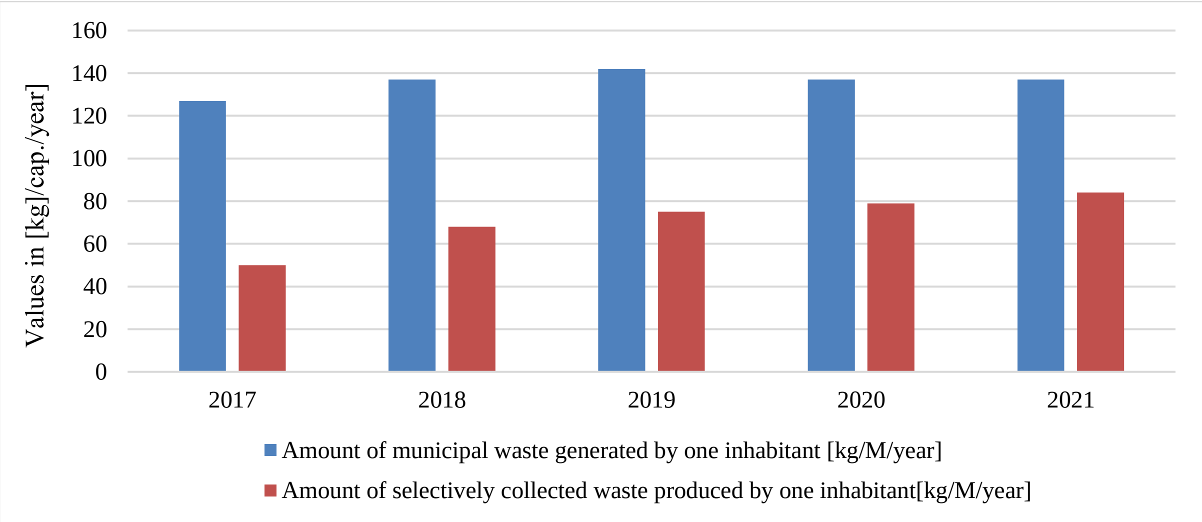

Figure 5. Amount of waste generated by one inhabitant in the Nowy Sącz county.
Source: own study based on data from the Central Statistical Office.

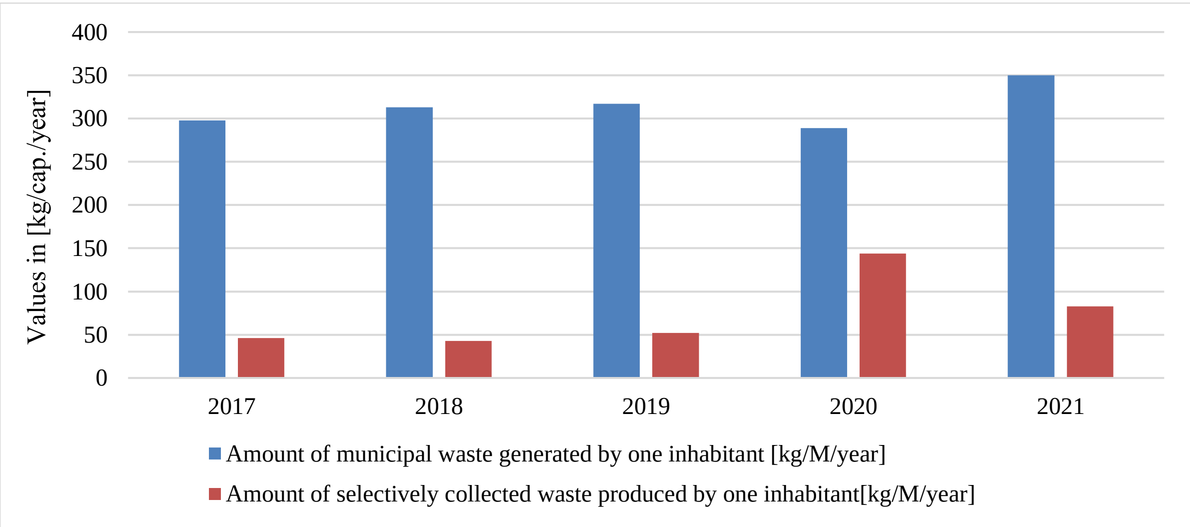

Figure 6. Amount of waste generated per capita in the city of Limanowa.
Source: own study based on data from the Central Statistical Office.

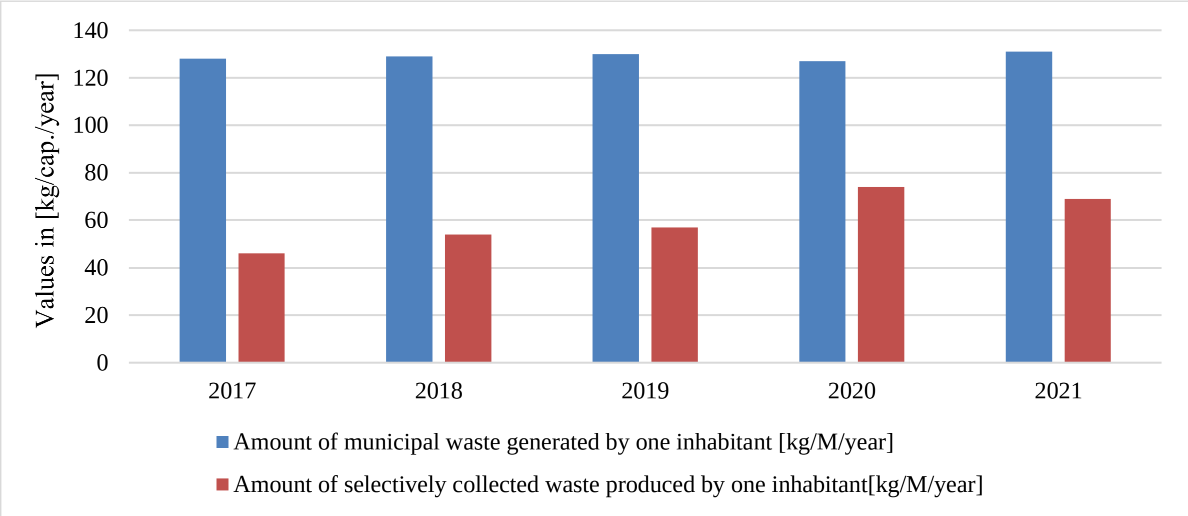

Figure 7. Amount of waste generated by one inhabitant in the Limanowa county.
Source: own study based on data from the Central Statistical Office.

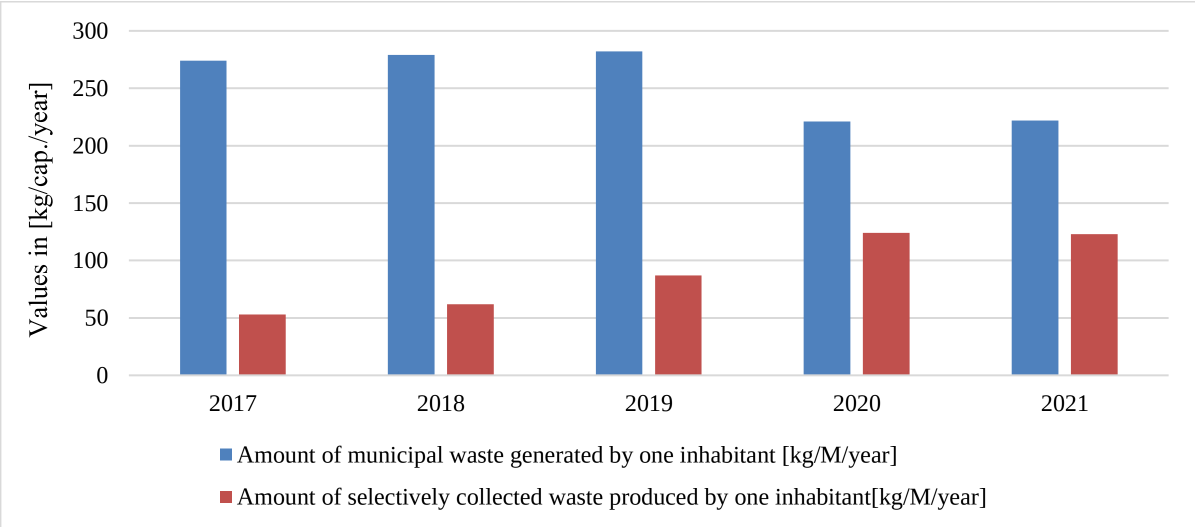

Figure 8. Amount of waste generated per capita in the city of Gorlice.
Source: own study based on data from the Central Statistical Office.

An increase in selectively collected municipal waste is noticeable in the Subregion. On the other hand, in the city of Gorlice and the Gorlice county, there is a noticeable decrease in the amount of collected municipal waste. This is most likely linked to a significant population decline. On the other hand, an increase in selectively collected waste is noticeable. This shows that society produces more and more waste and without proper management in this area, the environment would deteriorate significantly in a short time (Malinowski et al., 2009).

According to the data presented in Table 1, the largest percentage share in the composition of municipal waste is plastic waste – 30.34%, which in terms of calorific value is a very good indicator of 30.34 MJ/kg. Pichtel (2014) showed the calorific value of municipal waste of 9-14.5 MJ/kg. A lower share of plastic waste below 16% was shown Alwaeli (2015).

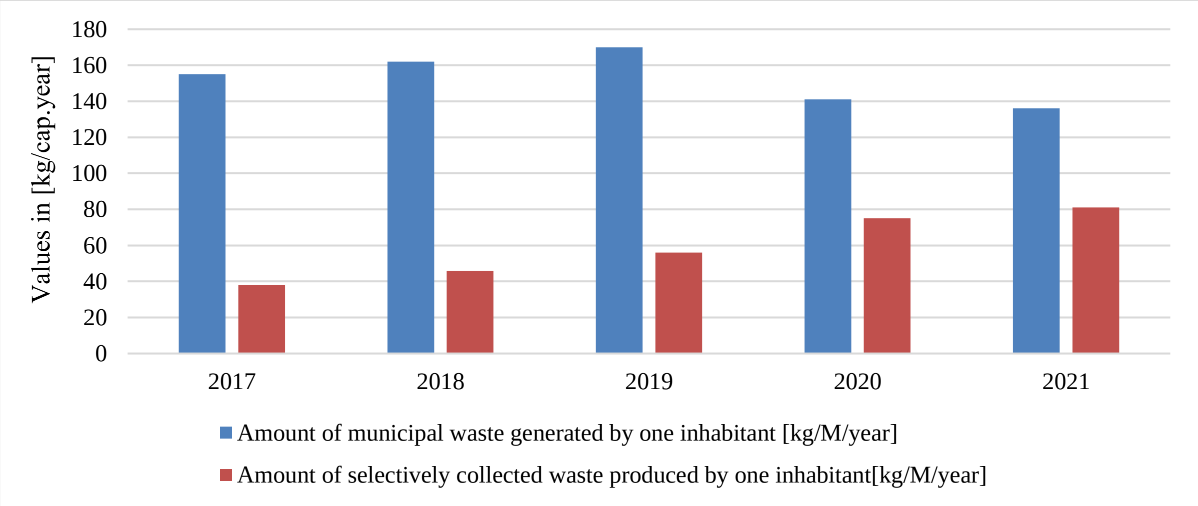

Figure 9. Amount of waste generated by one inhabitant in the Gorlice county.
Source: own study based on data from the Central Statistical Office.

The remaining amount of waste constitutes a smaller share of the total waste, although it has a high calorific value, which is important for the assumptions of thermal waste treatment installations. The share of 20.56% of glass waste in municipal waste intended for recycling is relatively high.

Table 1
Morphological composition of waste in the Sądecki Subregion

Morphological composition of municipal waste with a percentage share	[Mg]	[%]	Heating valu [MJ/kg]
Paper and cardboard	4,080.43	9.66	15.3
Glass	8,686.47	20.56	-
Plastic	12,821.38	30.34	35.1
Metals	60.72	0.14	-
Textiles	19.68	0.06	14.7
Dangerous	5.28	0.01	31.0
Packaging	3,432.61	8.12	16.2
Biodegradable	12,915.74	30.56	14.7
Rest	234.36	0.55	12.0

Source: own study based on data from the Central Statistical Office.

6. Assumptions of the installation for thermal waste processing

The components of the installation take into account the mass of waste generated in three cities and poviats in the Małopolskie Voivodship, i.e. the Nowy Sącz county and the city of Nowy Sącz, the Gorlice poviat together with the Gorlice city, and the Limanowa county with the Limanowa city.

Assumed installation parameters:

- mass of municipal waste in 2021 – 104 607,7 [Mg];
- number of inhabitants living in the Sądecki Subregion in 2021 – 573 918.

Table 2

Parameters of the furnace for thermal treatment of waste

Symbol	Unit	Value
M_p	Mg/h	11.9
b_m	$\frac{kg}{M \cdot rok}$	182.3
b_{obj}	$\frac{dm^3 \cdot kg}{M \cdot rok}$	4.46
G	$\frac{kg}{m^3}$	40.87
V_o	$\frac{m^3}{kg}$	5.86
L_o	$\frac{m^3}{kg}$	5.27
V	$\frac{m^3}{kg}$	6.9
U_1	MW	12.1
U_2	MW	14.9
η	%	81.0
E	kWh	40,827.6
E_m	kWh/person/year	623.17

Source: own study based on data from the Central Statistical Office.

where:

M_p – hourly processing power
I_o – amount of mixed waste
b_m – mass index of waste accumulation
b_{obj} – volumetric indicator of waste accumulation
G – bulk density
V_o – the volume of waste gases (exhaust gases) in stoichiometric combustion
L_o – theoretical volume of combustion air
λ – excess air factor = 1.2
U_1 – boiler power
U_2 – hearth power
E – energy generated in 1 hour.

The energy that will be possible to obtain from burning 1 Mg of waste will amount to 3,419.4 kWh. To maintain the continuity of the process, 11.9 Mg of waste will be incinerated every hour. The analysis shows that 40,827.6 kWh of electricity and heat will be generated per hour of operation of the installation. During one day, 979,862.4 kWh will be generated, which in one calendar year will amount to 357,649,776 kWh (Table 2). Thanks to the generated energy, every one of the inhabitants of the Sądecki Subregion will theoretically be able to obtain 623.17 kWh of energy per year.

7. Waste incineration technology

The waste incineration technology consists of a waste bunker, from which the waste is then poured into the combustion chamber using of an overhead crane, where the waste is thermally transformed. The next step is the production of steam in the heat recovery boiler, which drives the turbine, which generates electricity sent to power lines. The next step will be a hot water heater, where the water is heated and sent by pumps to the district heating network. The last stage is the flue gas purification installation, which includes activated carbon and lime milk, as well as a fabric filter that reduces dust emissions to the atmosphere (Figure 10).

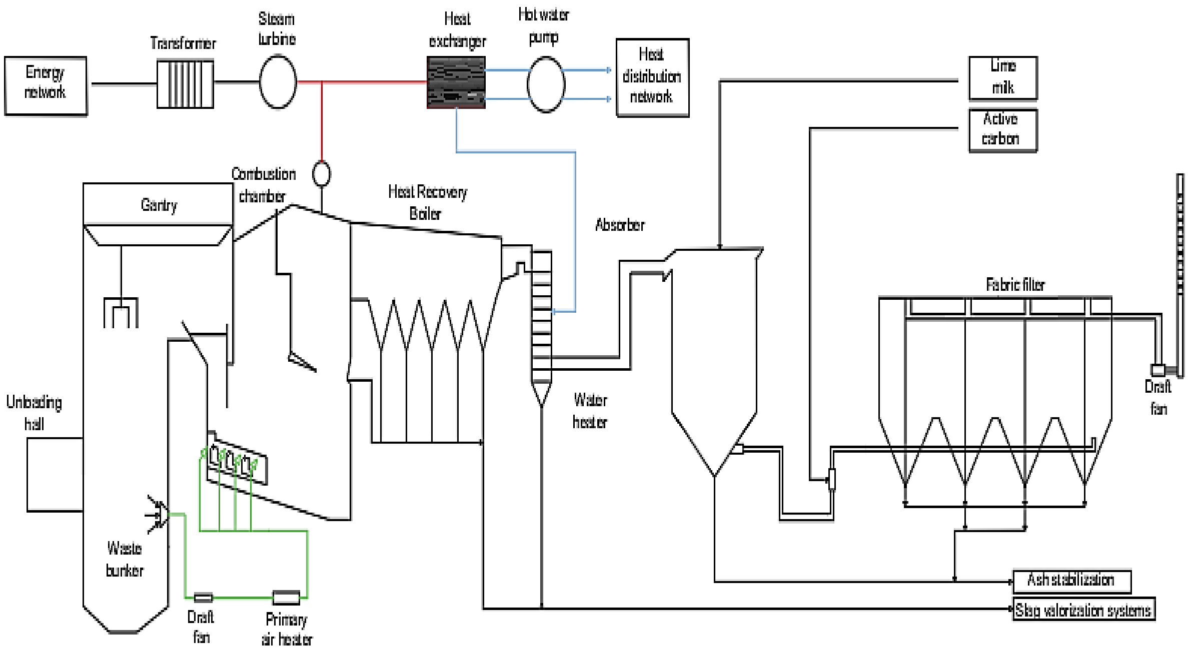

Figure 10. Technological scheme of the plant for thermal treatment of waste.
Source: own study based on data from the http://repolis.bg.polsl.pl (access: 10.05.2023).

Exhaust gas purification system

During the incineration of municipal waste, flue gases are generated, from which toxic substances must be eliminated as much as possible for the purified gases and dust to meet stringent emission standards.

One of the methods of neutralization of organic substances present in the volatile phase is the re-combustion of exhaust gases. This type of combustion takes place at a temperature of 800-1,200ºC, but care should be taken not to exceed the temperature of 1,400ºC, because at such high temperatures, as a result of the oxidation of nitrogen from the air, nitrogen oxides are formed, causing re-pollution of the atmosphere. Another solution is a biological filter, the most important element of which is the filter material on which microorganisms live. As the gases pass through the filter body, they are absorbed and then decomposed by the microorganisms living in the filter (Namiecińska et al., 2017).

For flue gas cleaning to be effective, a multi-stage system should be used, which will include (Figure 11):

- dedusting,
- removal of heavy metals;
- removal of nitrogen oxides;
- removal of organic compounds;
- removal of acid gases.

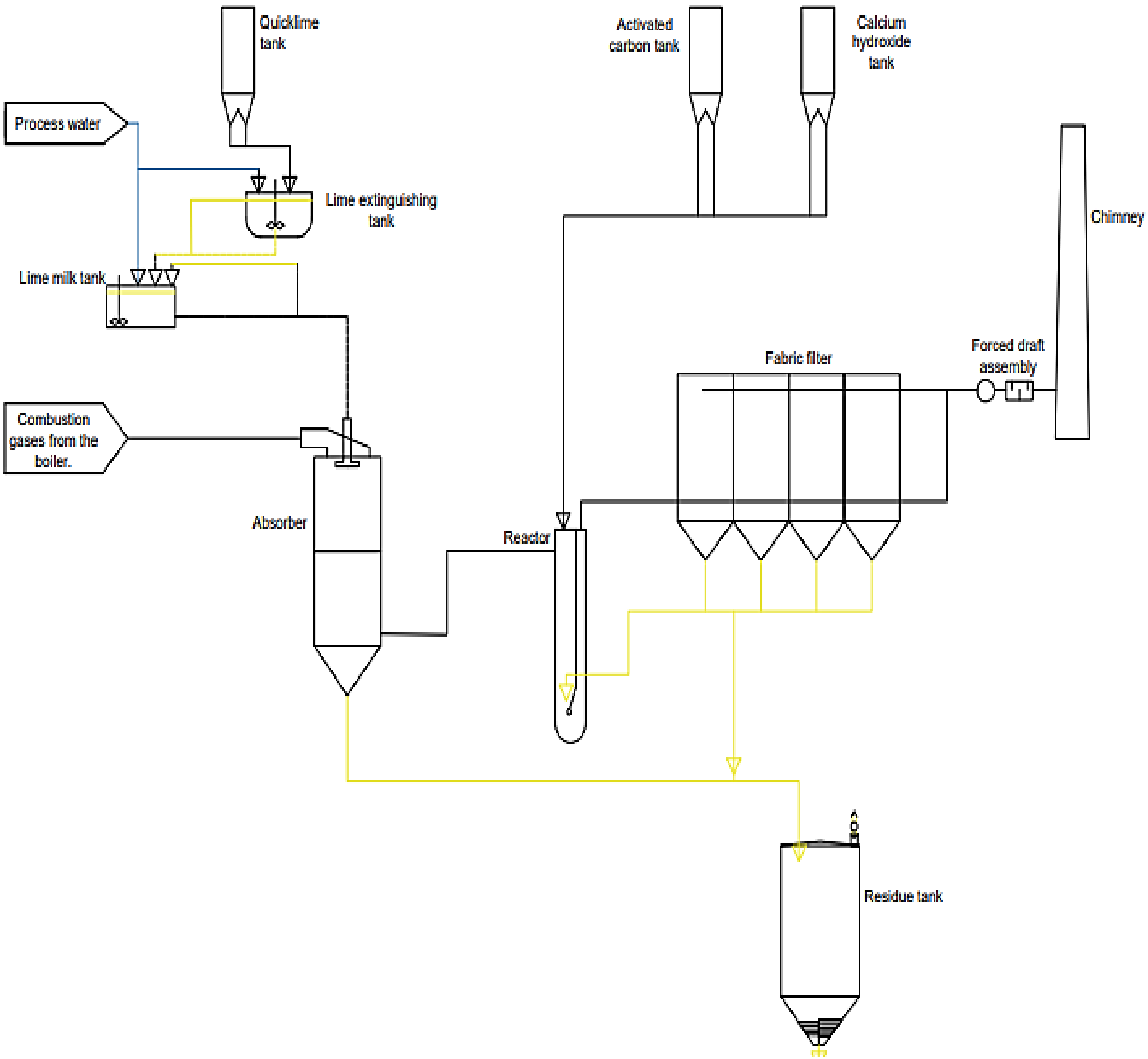

Figure 11. Scheme of flue gas treatment from a waste incineration plant.
Source: own study based on data from the http://www.portczystejenergii.pl (access: 10.05.2023).

The use of a multi-stage flue gas cleaning system can eliminate up to 99% of pollutants. The most important element in this process are fabric filters or electrostatic precipitators, as they reduce the emission of dust, which is a carrier of heavy metals into the environment.

In the planned plant, a fabric filter will be used for the thermal treatment of waste, which, thanks to the use of the most modern filtering elements resistant to high temperatures, can achieve a high degree of dust removal and reduce dioxin emissions into the atmosphere. To remove acid gases generated in the combustion process, a dry acid gas removal system using calcium hydroxide CaOH2 should be used. This process involves injecting a sorbent into the flue gas before the fabric filter. During the process, individual components of acid gases are removed (Wielgosiński, 2020).

Secondary waste management

After incineration, secondary waste is generated, which must be properly managed depending on its chemical composition. Slag and bottom ash will be used in road construction and building elements (Radwańska et al., 2020). Fly ashes, dust from dust extraction and gypsum must be collected in a hazardous waste landfill due to their chemical composition. Activated carbon used for flue gas cleaning can be incinerated with municipal waste. Scrap recovered during the incineration process will be sold to the smelter for re-production of materials.

Assumed capital expenditures

Assuming that 104,607.7 Mg/year of waste with a calorific value of 11.9 MJ will be recycled. The efficiency of the installation for generating electricity is estimated at 20%, and that of heat energy at 30%. Part of the generated electricity will be used for the installation's purposes. The thermal energy generated in the installation will be sold to MPEC (Miejskie Przedsiębiorstwo Energetyki Cieplnej). A significant cost of the installation is capital expenditure, which amounts to PLN 579,200,000. Annually, from the sale of heat and electricity, they will generate revenue of PLN 14,552,910 (Tables 3 and 4).

Table 3
Capital expenditures

Capital expenditures	Value	Unit
Machine	391	mln PLN
Electrical equipment	86.9	mln PLN
Construction work	57.9	mln PLN
Project management	43.4	mln PLN
Sum	579.2	mln PLN

Source: www.uigmbh.de (access: 10.05.2023).

Table 4
Operating costs and revenues

Operating costs and revenues	Value	Unit
Costs of raw materials	600	PLN/Mg
Compensation of employees	232,000	PLN/rok
Equipment maintenance	2.52	mln PLN/year
Sale of electricity	5,457,341	PLN/year
Sale of heat	9,095,569	PLN/year

Source: www.uigmbh.de (access: 10.05.2023).

8. Conclusions

After an analysis of the environmental conditions, as well as the spatial development plan of the installation for the thermal treatment of municipal waste, a plot was designated with an area of 17.5 ha in Nowy Sącz in the Biegonice district. The plot is located in an industrial district, which should help to reduce social conflicts related to the selection of the location of the waste incineration plant. The analysis showed a slight upward trend in the amount of municipal waste generated in the Subregion.

It was assumed that the maximum amount of waste to be neutralized in the incineration plant will amount to approx. 105,000 Mg/year. Plastics account for the largest share in the mass of municipal waste, 30.34%, which is important due to the calorific value of this waste – 35.1 MJ/kg. With a boiler efficiency of 81% and the amount of incinerated waste of 11.9 Mg/h, the equivalent amount of electricity and heat generated was 40,827.6 kWh. The sum of energy generated per year will amount to 357,649,776 kWh.

The estimated cost of the project was estimated at PLN 579,200,000.

It is assumed that the incineration plant will be equipped with a flue gas cleaning installation to reduce dust and gas emissions into the atmosphere. For the installation to be efficient, it will be advisable to apply a phased reduction of harmful emissions:

- dedusting;
- removal of heavy metals;
- removal of nitrogen oxides;
- removal of organic compounds;
- removal of acid gases.

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Comparison of the results of energy characteristics determined by the calculation and consumption method

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Abstract: The energy characteristics of a building are the amount of energy, obtained by calculation or measured, that is needed to meet the energy demand associated with the use of the building. At present, the energy performance certificate is prepared on the basis of a methodology for determining energy performance using a teleinformatics system in which a central register of energy performance is maintained. The scope of the study was to compare the energy performance characteristics of a selected dwelling determined by three methods: a calculation method for the assumed use and standard climatic conditions, a method based on the actual energy consumed and a method based on the heat balance. Part of the calculations was made using ArCADia TERMOCAD software, which, among other things, allows for the preparation of energy performance certificates for buildings and parts of buildings. Analysis of the results of calculations of the indices of final and primary energy demand obtained by the methods used shows significant differences. The discrepancy in the results of energy performance for the analyzed object is due, among other things, to the assumptions made, which in their current form are based on a pre-imposed methodology. In particular, the results obtained from the consumption method significantly depend not only on the structural, material and installation solutions of the building, but also on the individual behavior of the users, the number of residents, the climatic conditions prevailing during the analyzed period, as well as situations related to specific conditions of use. The indicators achieved by this method are therefore not fully objective. The consumption method, despite its ability to quickly produce an energy performance certificate, is heavily dependent on the individual behavior of the occupants, so it should be used to a very limited extent.
Key words: energy performance certificate, primary energy, final energy.

1. Introduction

An energy performance certificate is a document that specifies the amount of energy demand necessary to meet the energy needs associated with the use of a building or part of a building, i.e. energy for heating and ventilation, hot water preparation, cooling, and in the case of non-residential buildings, also lighting. The obligation to have an energy performance certificate for a building or part of a building in certain situations stems from European law (Directive, 2010). The purpose of the introduction of mandatory certification is to promote energy-efficient construction and increase public awareness of the potential for energy savings in buildings. Thanks to the information contained in the certificate, the owner, tenant or user of a building can determine the approximate annual energy demand and thus the maintenance cost associated with energy consumption. The rules for preparing and submitting energy performance certificates for buildings are set forth in the Law of August 29, 2014 on the Energy Performance of Buildings (Law, 2014).

An energy performance certificate is valid for 10 years from the date of its preparation. Certificates submitted before the effective date of the law (April 28, 2023) will remain valid for the period for which they were drawn up. The certificate will lose its validity before the expiration of this period if construction and installation works are carried out, as a result of which the energy performance of the building or part of the building will change (e.g., replacement of windows, replacement of the heat source, insulation of the building).

The certificate shall be drawn up on the basis of the methodology for determining energy performance using an ICT system, in which a central register of energy performance is maintained. The methodology is defined by the Regulation of the Minister of Infrastructure and Development of February 27, 2015 on the methodology for determining the energy performance of a building or part of a building and energy performance certificates (Błaszczyński, Ksik, 2020).

The energy performance of a building is understood as that amount of energy, obtained by calculation or measured, which is needed to meet the energy demand associated with the use of the building (Fedorowicz, Pokorska-Silva, 2016).

The rules for determining the energy performance of a building are formulated in the aforementioned regulation. This act specifies how to determine the energy performance, the indicators of annual energy demand and annual demand for specific types of energy. There are two main methods for determining the energy performance of a building: the calculation method and the consumption method. The first is based on the standard use of a building or part of it. The second, on the other hand, is based on the amount of energy actually consumed.

Energy demand values for individual facilities should not form the basis for generalizations. In practice, a calculation method is more often used, in which they are determined:

- coefficient of heat loss by penetration and ventilation;
- Monthly heat loss through penetration and ventilation;
- Monthly solar and internal heat gains and their utilization factor;
- The monthly utility heat demand for heating and ventilation;
- annual utility energy demand for heating and ventilation$Q_{H,nd}$;
- annual energy demand for domestic hot water preparation $Q_{W,nd}$;
- annual utility energy demand for cooling $Q_{C,nd}$;
- annual utility energy demand Q_u

$$Q_u = Q_{H,nd} + Q_{W,nd} + Q_{C,nd} \tag{1}$$

- EU annual utility energy demand index;
- The average seasonal efficiency of the heating and cooling system and the annual efficiency of the hot water preparation system;
- annual final energy demand supplied to the building for the heating system $Q_{k,H}$ domestic hot water preparation $Q_{k,W}$, cooling $Q_{k,C}$ and the embedded lighting system $Q_{k,L}$;
- annual auxiliary energy demand $E_{el,pom}$;
- annual final energy demand Q_k

$$Q_k = Q_{k,H} + Q_{k,W} + Q_{k,C} + Q_{k,L} + E_{el,pom} \tag{2}$$

- EK annual final energy demand indicator;
- Non-renewable primary energy input coefficients;
- annual demand for non-renewable primary energy for the heating system $Q_{p,H}$, domestic hot water preparation $Q_{p,W}$, cooling $Q_{p,C}$ and the embedded lighting system $Q_{p,L}$;
- annual demand of non-renewable primary energy Q_p

$$Q_p = Q_{p,H} + Q_{p,W} + Q_{p,C} + Q_{p,L} \tag{3}$$

- index of annual demand for non-renewable primary energy EP.

Energy performance is determined by the values of annual demand indicators (Regulation, 2015):

- non-renewable primary energy:

$$EP = \frac{Q_p}{A_f}\ [kWh/(m^2 \cdot rok)] \tag{4}$$

- final energy:

$$EK = \frac{Q_k}{A_f}\ [kWh/(m^2 \cdot rok)] \tag{5}$$

- utility energy:

$$EU = \frac{Q_{ku}}{A_f}\ [kWh/(m^2 \cdot rok)] \tag{6}$$

where:

A_f – area of rooms with controlled air temperature (heated or cooled area).

The consumption method can be used to determine the energy performance of existing buildings not equipped with a cooling system, in operation, for at least three years, and is intended to assist in the evaluation of existing buildings, for example, with incomplete technical documentation. The consumption method is used when:

- for heating or hot water preparation, the building is supplied by district heating or gas;
- consumption of system heat is billed on the basis of heat meter readings, and natural gas is billed on the basis of gas meter readings, while consumption of hot water is billed on the basis of water meter readings;
- there are documents proving the actual consumption of heat or natural gas for the last 3 years preceding the preparation of the energy performance certificate;
- no construction work affecting their energy performance was carried out during the period indicated above;
- they are not equipped with a cooling system;
- natural gas is used exclusively for heating or hot water preparation, and its consumption is measured by a separate gas meter;
- it is possible to determine the area of buildings with regulated air temperature.

In the consumption method, the annual demand for final energy supplied to a building or part of a building for the heating system Qk,H is determined according to the formula:

- For district heating:

$$Q_{k,H} = \frac{C_{H3}}{3}\ [kWh/rok] \tag{7}$$

where:

C_{H3} – The sum of network heat consumption for heating purposes for the last 3 years preceding the issuance of the energy performance certificate.

- For natural gas:

$$Q_{k,H} = \frac{\frac{C_{H,l} \cdot W_0}{3.6} + C_{H,m}}{3}\ [kWh/rok] \tag{8}$$

where:

$C_{H,l}$ – The sum of natural gas consumption for heating purposes for the last l years preceding the issuance of the energy performance certificate, [m^3]

W_0 – calorific value of natural gas [MJ/m^3]

$C_{H,m}$ – The sum of natural gas consumption for heating from the last m years preceding the issuance of the energy performance certificate, in the case of accounting for gas consumption in a unit of energy contained in the supplied gaseous fuel [kWh].

m – the number of consecutive years, in the case of accounting for gas consumption in a unit of energy contained in the delivered gas fuel, except that: $m = 3 - l$.

Similarly, the annual final energy demand supplied to the building or part of the building for the domestic hot water preparation system is determined $Q_{k,W}$

The graphical evaluation of energy performance (regardless of the method) is a color scale (Figure 1).

On the scale, arrows indicate the calculated EP value and the EP value required for a new building, as determined by the Technical Conditions for Energy Certificates for Buildings (Robakiewicz, 2015).

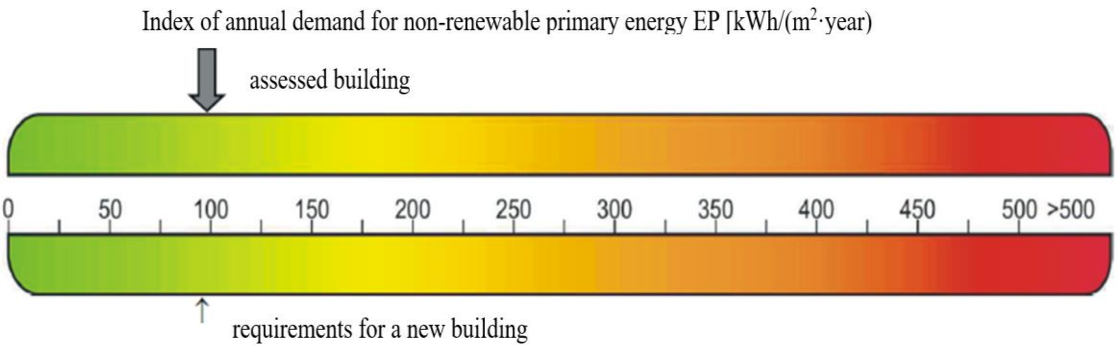

Figure 1. Scale of the annual demand for non-renewable primary energy EP.
Source: Rozporządzenie Ministra Infrastruktury i Rozwoju z dnia 27 lutego 2015 r. w sprawie metodologii wyznaczania charakterystyki energetycznej budynku lub części budynku oraz świadectw charakterystyki energetycznej (Dz.U. z 2015 r., poz. 376).

2. Purpose and scope of the study

The scope of the study was to compare the energy efficiency characteristics for a part of the building (apartment), determined by the calculation method (Met_o) and consumption method (Met_z), as well as the heat balance method (Met_b).

A residential unit with an area of 38.82 m^2 located in Krakow was selected for analysis. The building in which the apartment is located was built in 2019. It is a middle apartment on the 3rd floor. The corridors and staircase are heated. The technical condition of the building is described as very good. The premises are permanently inhabited by 2 adults and used all year round. The general parameters of the object are summarized in Table 1.

Table 1
Facility parameters

Specification	Description
Location	Kraków
Utility program	Central apartment, on the 3rd floor: room with annex, 1 bedroom, bathroom and hall
Orientation	Exterior wall in southwest orientation
Area and volume indicators	Usable area of 38.82 m^2 Heated area of 38.82 m^2 The volume of the apartment 99.57 m^3
Construction and material solutions	Apartment in a multi-family building; the building has six floors above ground; building structure reinforced concrete with masonry elements; exterior wall of the apartment: reinforced concrete with ceramic hollow blocks insulated with polystyrene, interior walls reinforced concrete with ceramic hollow blocks, interstory ceilings – reinforced concrete; exterior windows, double-paned
Technical systems	Heating and hot water preparation system: Municipal district heating network Ventilation: mechanical exhaust

Source: own elaboration.

The stages of the analysis included:

- thermal calculations;
- heating and ventilation;
- domestic hot water.

Characterization by the calculation method for the assumed use and standard climatic conditions and by the consumption method was carried out using ArCADia TERMOCAD v.8 software, which, among other things, allows for the preparation of energy performance certificates for buildings and their parts.

3. Energy demand analysis

3.1. Energy performance results obtained by the method based on standard usage (calculation method)

In the first step of the analysis, the systems present in the analyzed facility were determined, as well as basic parameters such as purpose, location, and climate zone. Climatic data was needed to calculate seasonal heat demand. Table 2 summarizes the average temperatures for the apartment's location zone adopted in the program for determining energy performance by calculation. Duration of heating season tsG: 6024.21 [h].

Table 2
Heating season and average temperature values adopted for calculations in ArCADia TERMO program

Months	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Temperature[°C]	-1.3	-2.6	3.2	8.3	13.4	18.2	17.5	17.5	13.8	9.3	1.9	-0.8
Time [h]	744	672	744	720	391	0	0	0	543.1	744	720	744
Days	31	28	31	30	16.3	0	0	0	22.6	31	30	31

Source: own elaboration.

Table 3
Technical systems and annual amount of energy carrier consumed (Met_o)

System	System components	Description	Seasonal average efficiency
Heating system	Heat generation	Compact district heating node	0.99
	Heat transfer	central heating from a local source	0.96
	Heat accumulation	Without tray	1.00
	Regulation and use of heat	Water heating with radiators	0.89
Hot water preparation system	Heat generation	Nodes equipped with weather automation	0.99
	Heat transfer	Central water heating	0.77
	Heat accumulation	Without tray	1.00

Source: own elaboration.

Further, all partitions present in the assessed building were defined and calculations of the partitions' Rc resistance and U-factor were made. Then the thermal zones were defined, which were used to calculate the seasonal heat demand.

Once the thermal calculations were made, the facility's heat supply and distribution method were determined. This allowed the determination of the individual efficiencies of the heating system (Table 3), necessary for calculating the annual final energy demand for the heating and ventilation system.

Based on the design documentation, the energy demand was determined using the calculation method for the analyzed apartment (Table 4).

Further, based on the assumptions about the heating system derived from the methodology and the temperature for the particular climate station adopted in the program, energy performance indices were calculated (Table 5). Two additional cases of internal temperature were considered here, i.e. 20°C and 23°C.

Table 4

Calculated annual quantity of energy carrier or energy consumed

Technical system	**Type of energy carrier or energy**	**Quantity of energy carrier or energy** $[kWh/(m^2 \cdot year)]$
Heating	District heating from cogeneration	37.96
	Electricity	0.21
Domestic hot water preparation	District heating from cogeneration	36.11
	Electricity	0.10

Source: own elaboration.

Table 5

Energy performance indicators – calculation method (Met_o)

Description **Adopted internal temperature**	**Met_o 20 C°**	**Met_o 23 C°**
Annual utility energy demand index, EU $[kWh/(m^2 \cdot year)]$	59.6	71.6
Index of annual final energy demand, EK $[kWh/(m^2 \cdot year)]$	74.4	88.6
Index of annual demand for non-renewable primary energy, EP $[kWh/(m^2 \cdot year)]$	60.5	68.3

Source: own elaboration.

The values of EP indicators are in accordance with the current standards as of the date of obtaining a permit to use this facility. Currently, in order to meet the requirement of the technical and building regulations (WT2021), the EP indicator should not be greater than 70 kWh/m^2 year.

3.2. Energy performance results obtained using the method based on actual energy consumed

In the next step of the analysis, the energy performance of the apartment was determined using a method based on the energy actually consumed. The analyzed apartment meets the requirements specified in the regulation for the application of this method.

Energy consumption data for heating and hot water preparation for the 3-year period are summarized in Table 6.

Table 6

Energy consumption over 3 years [kWh]

	2020	**2021**	**2022**
Heating and hot water preparation system	2,919.61	2,641.91	2,502.95

Source: own elaboration.

During the analyzed period, the apartment was used by 2 adults. The average temperature during the heating period maintained in the apartment is about 23-24ºC, the average monthly water consumption is 2.77 m^3. The final energy demand for central heating and hot water was calculated jointly for both systems. The value of the non-renewable primary energy input coefficient for the facility was assumed based on data from the district heating network of MPEC S.A. in Krakow. This coefficient amounted to – 0.8 in 2022.

In the case of a joint central heating and hot water system, neither the value of the EU utility energy index nor its sub-values are calculated. The results obtained are summarized in Table 7.

Table 7

Energy performance indicators – consumption method Met_z

Index of annual final energy demand, EK $[kWh/(m^2 \cdot rok)]$	88.5
Index of annual demand for non-renewable primary energy, EP $[kWh/(m^2 \cdot rok)]$	71.4

Source: own elaboration.

The primary energy demand indicators of the analyzed apartment, determined by the consumption method, are not within the range of current WT2021 requirements $EP_{max} = 70\ kWh/(m^2\text{-}year)$.

3.3. Energy performance results obtained by the heat balance method (analytical calculations)

Based on the temperature data taken into account during the calculations carried out using ArCADia software and real data obtained from a weather station suitable for the location of the analyzed object (Table 8), calculations were made of the demand for heating and hot water preparation.

Table 8

Average temperatures for the city of Krakow in 2020-2022 [^0C]

	2020	2021	2022
January	1.6	-0.5	1.1
February	4.5	-0.3	3.9
March	5.5	3.9	4.0
April	10	7.0	7.7
May	12.1	13.3	15.7
June	18.7	19.8	20.4
July	19.7	21.9	20.4
August	20.9	18.1	20.9
September	15.5	14.5	13.3
October	10.5	9.0	11.4
November	5.3	5.4	4.7
December	1.4	0.2	0.7

Source: own compilation based on data from https://meteomodel.pl/dane/srednie-miesieczne/?imgwid=250190390&par=tm&max_empty=0 (access: 10.05.2023).

For the purpose of estimating the demand for DHW preparation, the relationship was used:

$$Q_{dsr} = n \cdot Q_c \tag{9}$$

$$Q_{hsr} = \frac{Q_{dsr}}{\tau} \tag{10}$$

$$Q_{hmax} = Q_c \cdot N_h \tag{11}$$

where:

Q_{dsr} – average daily hot water demand, taken at 110 dm^3/day
n – number of residents (2 people were admitted)
Q_c – unit consumption of hot water (assumed: 120 l/day/person)
τ – Time of use of hot water (assumed 18 h)
N_h – coefficient of hourly irregularity of water distribution, calculated based on formula 12.

$$N_h = 9.32 \cdot n^{-0,244} \tag{12}$$

Heating water to a usable temperature requires the supply of a heat flux Φ calculated based on equation 13.

$$\Phi = Q \cdot c_p \cdot \rho \cdot (t_c - t_z) \tag{13}$$

where:

Φ – heat demand
Q – water demand
c_p – specific heat of water (4200 J/kg K)
ρ – density of water (980 kg/m^3).

Heat losses in winter were calculated based on the difference in temperature on both sides of non-transparent partitions (exterior walls) and the thermal transmittance, based on formula 14. For transparent partitions (exterior windows), heat gains from insolation were additionally taken into account (formula 15).

$$Q_{sc} = F \cdot U \cdot \left(t_z - t_p\right) \tag{14}$$

$$Q_{ok} = F\left[\Phi_1 + \Phi_2 + \Phi_3 \cdot (k_c \cdot R_s \cdot I_{cmax} + k_r \cdot R_c \cdot I_{rmax}) + U \cdot \left(t_z - t_p\right)\right] \tag{15}$$

where:

Q_{ok}, Q_{sc} – heat loss through non-transparent and transparent partitions
F – partition surface
Φ_1, Φ_2, Φ_3 – coefficients determining the respective share of glazed area, correction for altitude and type of glazing
k_c, k_r – accumulation factors
R_s, R_c – proportion of sunlit and shaded area
I_{cmax}, I_{rmax} – maximum values of total and diffuse radiation
U – heat transfer coefficient
$\left(t_z - t_p\right)$ – the temperature difference recorded on both sides of the partition.

The heat flux supplied to the premises for ventilation purposes was calculated from relation 16 based on the volume flow of air and the temperature difference between the supplied air and the temperature prevailing inside the ventilated premises

$$Q_w = V \cdot c_p \cdot \rho \cdot (t_c - t_z) \tag{16}$$

where:
Q_w – heat flux for ventilation purposes
V – volume flow of air supplied to the premises
c_p – specific heat of air
ρ – air density
$(t_c - t_z)$ – temperature differential.

The results of the energy performance determined by the heat balance method are summarized in Table 9. Analogous to the calculation method, two cases of internal temperature were considered here, i.e. 20°C and 23°C.

The above methodology for determining a building's energy demand, as noted earlier, takes into account both the number of residents (n) and the average monthly actual temperature values for a given location. The authors, in this step of the study, additionally carried out calculations taking into account the average temperatures of a given climatic zone (adopted in the ArCADia TERMOCAD program). The results of such simulation are summarized in Table 10.

Analysis of the results in the table above shows that the results for the two temperature ranges coincide, confirming the correctness of the temperature values adopted for the climate zones used in the calculations with the energy certification software. The 1.9°C lower outdoor temperature is taken into account by the ArCADia software, which translates into a more restrictive calculation of the EP index in relation to the temperature data recorded during the analyzed period (there were mild winters in 2022 to 2022).

Table 9
Energy performance indicators – heat balance method (Met_b)

Description	**Met_b**	**Met_b**
Adopted internal temperature	20°C	23°C
Annual utility energy demand index, EU $[kWh/(m^2 \cdot year)]$	66.1	70.5
Index of annual final energy demand, EK $[kWh/(m^2 \cdot year)]$	69.0	73.4
Index of annual demand for non-renewable primary energy, EP $[kWh/(m^2 \cdot year)]$	55.2	58.7
Calculated annual amount of energy carrier or energy consumed for the heating system $[kWh/(m^2 \cdot year)]$	32.2	36.7
Calculated annual amount of energy carrier or energy consumed for heating system for hot water preparation system $[kWh/(m^2 \cdot year)]$	33.8	33.8

Source: own elaboration.

Table 10
Energy performance indicators for different outdoor temperatures and at an indoor temperature of 20°C

Indicator	Met_b Including average temperatures for the climate zone (adopted in ArCADia software)	Met_b Taking into account the average actual temperatures for the location of the apartment
EU $[kWh/(m^2 \cdot year)]$	73.0	66.1
EK $[kWh/(m^2 \cdot year)]$	75.2	69.0
EP $[kWh/(m^2 \cdot year)]$	60.6	55.2

Source: own elaboration.

4. Conclusions

Calculations of indices of final and primary energy demand were carried out using three methods: calculation, consumption and heat balance for a two-room apartment in the location of the city of Cracow.

Based on the analysis of the calculation results, the following conclusions were made:

- showed differences in the results obtained by the consumption method Met_z and the calculation method Met_o, which amounted to 15-22% (assuming an indoor temperature of 200°C in the calculations) and 5% (assuming an indoor temperature of 230C in the calculations). The rate of final energy demand for heating and hot water preparation in the case of the consumption method deviates from the value of the rate determined by the calculation method (Met_o) for typical usage conditions and external conditions determined for the weather station of the locations in question.
- These discrepancies are due to the assumptions made, which in the current form of the methodology are imposed in advance. The consumption method, on the other hand, is based on the value of average energy consumption and the parameters of the heating system, so it is not fully adequate for comparisons. The result obtained from the consumption method significantly depends not only on the construction, material and installation solutions of buildings, but also on the individual behavior of users, the number of residents and climatic conditions prevailing during the analyzed period, as well as situations related to specific conditions of use (in particular, the maintained indoor temperature, air exchange rate).
- The differences in EP and EK results obtained by the Met_z calculation method and the Met_b heat balance method are at the level of 18-22%. Precise comparison of these results by analogy with the earlier comment is not justified due to the very simplified way of determining the energy performance of a building by the consumption method.

- The rate of final energy demand for heating and hot water preparation determined by the calculation method (Met_o) for typical usage and outdoor conditions determined for the weather station of the locations in question is slightly different from the rate determined by the balance method (Met_b), both for actual temperature data and those assumed in the Arcadia program.
- The differences in the results obtained by the Met_o calculation method and the Met_b heat balance method are at the level of 8-11%. It has been shown that the reason for this is the deviation of the values of average monthly temperatures actual for a given location of the building from those included in the ArCADia program, as well as the use of a simplified method of monthly calculation of heating energy demand.
- Due to the slight deviation, the correctness of the assumed temperature values for the climate zone used in the calculations with ArCADia TERMOCAD software was demonstrated in relation to the actual values (average monthly temperatures for the site location).

In summary, the consumption method, despite its ability to quickly produce an energy performance certificate, is heavily dependent on the individual behavior of the occupants, so it should be used to a very limited extent. The indicators achieved by this method are therefore not fully objective, i.e. related only to the technical conditions of the building and the heat source. This may result in a decrease in confidence in the energy performance certificate. By design, energy performance certificates are intended to be a tool for improving the energy efficiency of buildings, but the incomprehensibility and errors of the certificates mean that they do not generate action to improve the energy efficiency of buildings, but become only a formal obligation.

The analyzed example, in which fairly convergent results were obtained using different methods of determining energy performance, is a single case study, so the conclusions drawn should not be considered as a generalization for every object.

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Complementary energy system of a single-family house

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Abstract: The dependence of modern household appliances on electricity means that their effectiveness and reliability depend to a large extent on the continuity of electricity supply and its quality. This article presents a complementary energy system for a single-family house. The construction and purpose of individual blocks of the system were discussed, and the results obtained during the annual operation of the system were discussed.
Key words: solar cells, energy storage system, photovoltaic.

1. Introduction

The growing expectations regarding the reduction of energy consumption costs, the need to transmit electricity over long distances, the associated losses and the energy crisis caused by the recent pandemic and the ongoing war in Ukraine result in the constant search for new solutions. One of them may be the use of environmentally friendly RES (Renewable Energy Sources), energy storage as well as maximizing the self-consumption of energy by prosumers. Of course, the problem of energy storage remains, in this case it is possible to use distributed energy storage (ME). These storages can be combined with RES systems, which seems to be the most beneficial.

2. The concept of using the system

The aim of the project was to build and test in real conditions a complementary energy system for a single-family house. The complementarity of this system consists in the mutual complementation of its individual elements in the field of energy production, storage and consumption (Bocklisch, 2015; Jafari, Botterud, Sakti, 2022; Maleczek, Malicki, Szczepaniak, 2019; Moseley, Garche, 2014; Worku, 2022; Rangel-Martinez, Nigam, Ricardez-Sandoval, 2021; Zakeri, Syri, 2015). The installation was designed and built as independent photovoltaic systems: prosumer and off-grid. Operational tests confirming the validity of the concept in the field of: production, energy storage and self-consumption also included the conversion of electricity into thermal energy for heating the building and obtaining hot utility water. The adopted solutions took into account the aspect of system reliability as well as the simplicity of implementation and relatively low investment costs compared to other solutions. An additional advantage of the installation is the ability to operate the off-grid system during a power outage from the operator.

3. System components

According to the assumptions presented in Figure 1 above, the system consists of the following systems: generation, storage and consumption of energy. The generation systems include two photovoltaic systems: prosumer with a capacity of approx. 6.9 kWp and island with a capacity of 1.35 kWp.

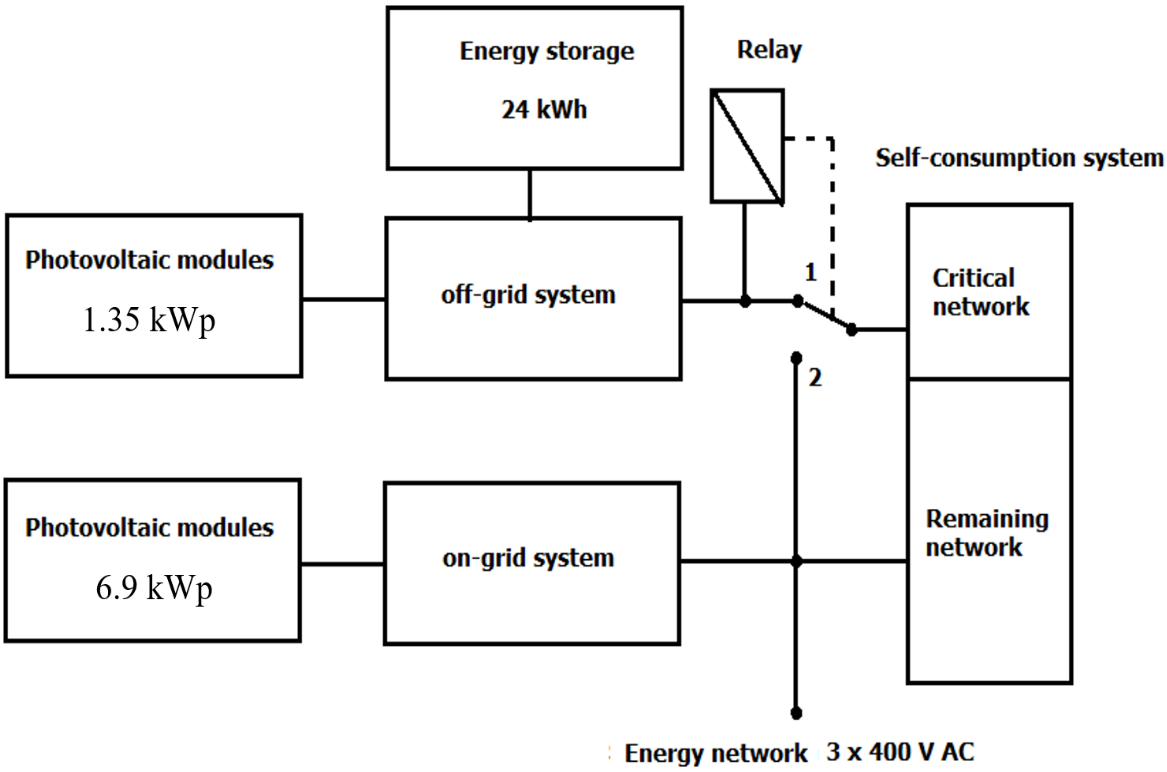

Figure 1. The concept of a complementary energy system.
Source: own elaboration.

The prosumer system (Figure 2) has two photovoltaic circuits: the first with a capacity of approx. 3.7 kWp, located on the ground and facing south, and the second with a capacity of approx. 3.2 kWp located on the roof of the building facing west. The three-phase inverter with a power of 6.6 kWp is connected via a protection system on one side to the photovoltaic modules and on the other to the power grid. There is a typical, very common solution (Figure 3). In addition, the system is equipped with an external three-phase energy meter. The connection diagram is widely known and will not be presented here.

Figure 2. Photovoltaic circuits of the prosumer system.
Source: own elaboration.

The off-grid system is completely independent of the prosumer system and has its own single-phase inverter with a power of approx. 3 kWp (pure sine wave) equipped with an energy storage voltage supervision system. This solution results from three aspects: reliability, functionality and cost. The functionality in this solution is understood as the independent operation of both systems. The nominal voltage of the main bus on the DC side is 96 V. An energy storage with a capacity of 24 kWh, made as a two-circuit system, is connected to the system. In the first circuit, there are 16 12 V acid batteries with a capacity of 100 Ah, made in AGM technology (in series-parallel connection, which gives the resultant 96 V 200 Ah). In the second circuit, there are 16 12 V acid batteries with a capacity of 20 Ah, made in the VRLA technology (in series and parallel connection, which gives the resultant 96 V 40 Ah).

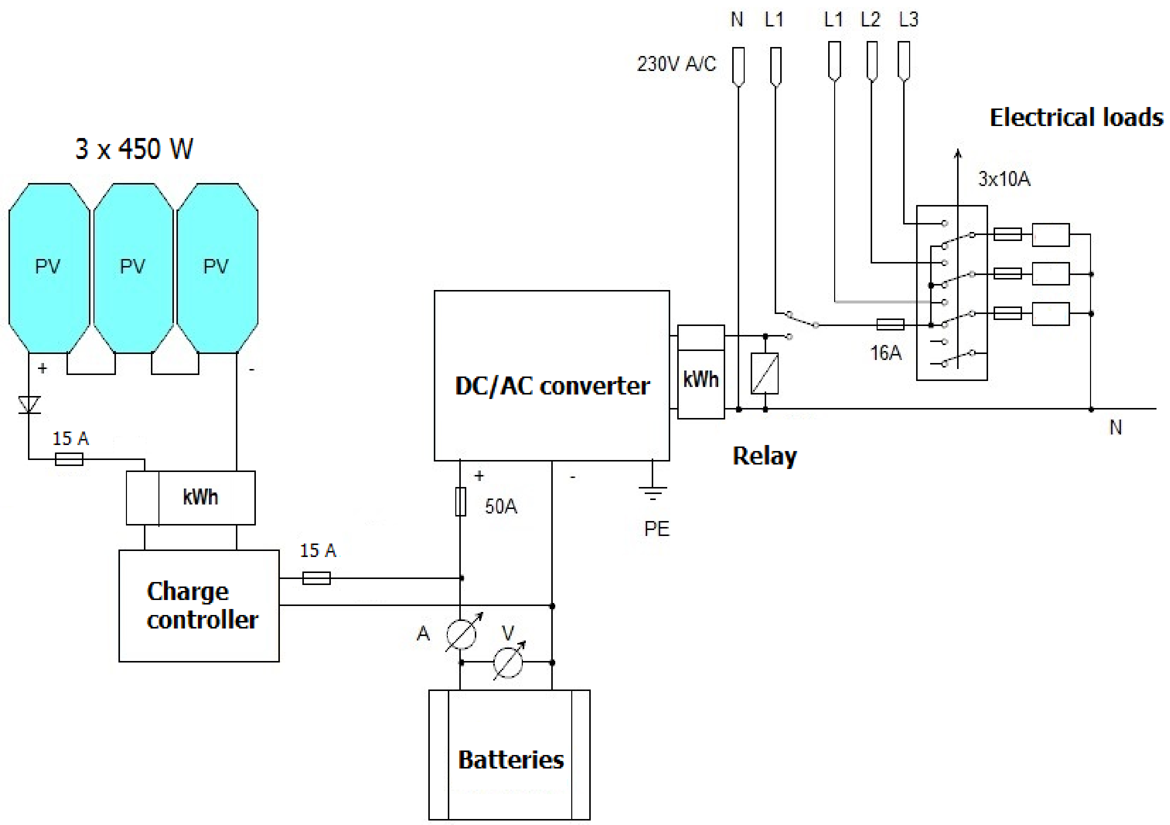

Figure 3. Block diagram of the off-grid system.
Source: own elaboration.

Due to the difficulties in purchasing a charging regulator for the 96 V DC bus, a dedicated impulse regulator with an input voltage of up to 120 V and a current of up to 40 A was designed and manufactured (Figure 4, Figure 5).

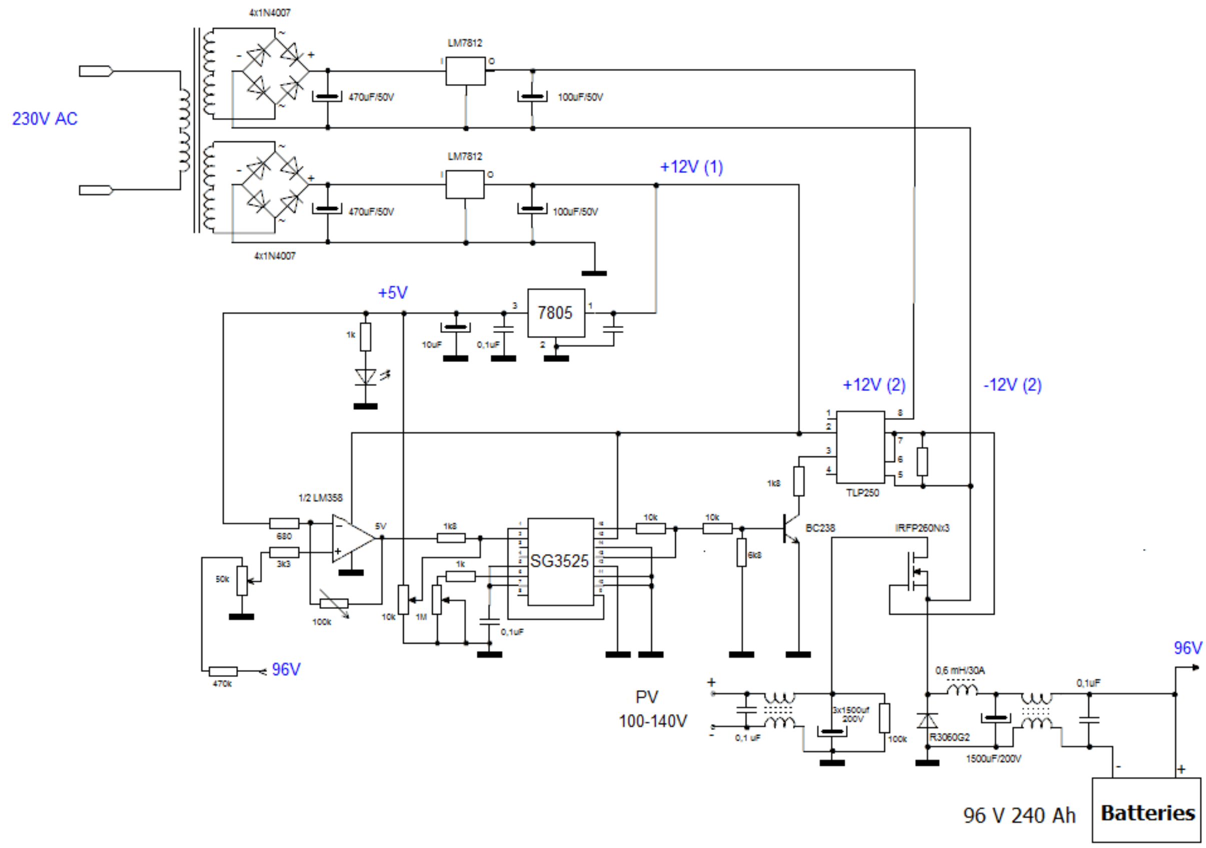

Figure 4. Schematic diagram of a pulse charge regulator.
Source: own elaboration.

Figure 5. The controller is under measurement and ready for use.
Source: own elaboration.

The energy obtained from photovoltaic modules and received from the off-grid system is read from panel meters (DC energy meter and single-phase AC electricity meter). The system (which is basically a large UPS system) powers all "sensitive" receivers such as: a refrigerator, a gas boiler, a TV set and the necessary internal and external lighting of the building. Both photovoltaic systems work independently; prosumer 24/7, while island 24/7 from April to October, in other months only during the day. The periodic operation of the off-grid system results from the fact that the discharge depth is limited (to approx. 30% of the available capacity), which ensures long battery life and guarantees the availability of energy in the event of failures at the electricity supplier. With a large amount of energy produced, in order to meet the economic aspect of the investment, it must be used in the maximum amount. This is understood here as the maximization of the so-called self-consumption. In order to meet this condition, the existing heating system (gas boiler and fireplace) was expanded with two air-conditioners (working mainly as heat pumps) and instantaneous utility water heaters. Most household and garden equipment (induction and resistance heating plates, mowers, trimmers, etc.) is also powered by electricity. Producing your own energy is not the only condition for low costs of using a house. Very important aspects are efficient insulation of the building (walls and ceilings) and its location ensuring exposure to the south side (air-conditioner exchangers should also face south. These conditions are met by the building under consideration. Only the recuperation system is missing, it was not included in the design phase.

4. System research

Tests and measurements were carried out during one last year of operation of the prosumer system and during the eight-month period of operation of the off-grid system. First of all, parameters such as electricity production in both inverter systems (prosumer and off-grid) and energy balance taking into account self-consumption were recorded. The batteries used in the energy storage were also tested, as well as an attempt to use a wind turbine as well as the impact of snowfall on the production of electricity.

4.1. Research of the energy yield of the system

These tests were carried out on the basis of readings from inductive energy meters (alternating current – three-phase prosumer system and single-phase for off-grid) and an electronic direct current meter for the off-grid system. The energy production of the prosumer system includes all energy without distinction between self-consumption and energy transferred to the operator. Its total value (according to Figure 6) is 6940 kWh.

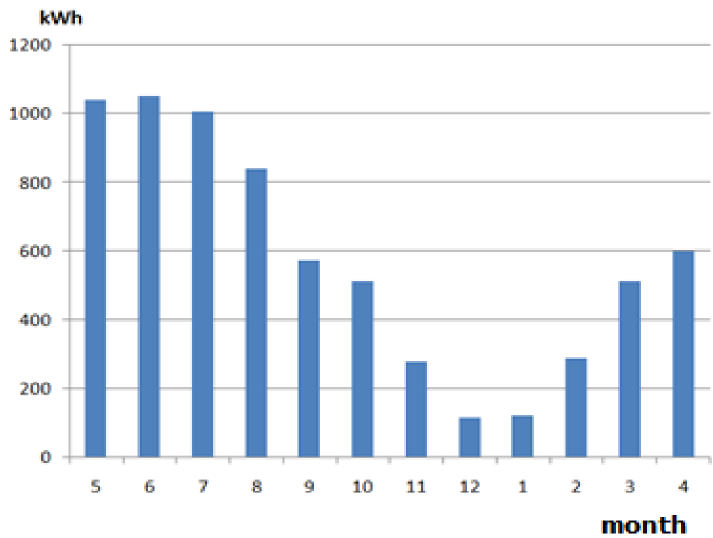

Figure 6. Energy produced in the prosumer system during the year (in the months: from May to April).
Source: own elaboration.

In the case of the off-grid system, total (over the entire test period) readings of the DC meter located in the circuit of photovoltaic modules and monthly readings of the AC meter located at the output of the inverter and showing the energy consumption of receivers of sensitive circuits were recorded (Figure 7). By comparing both energy values (DC) and the sum of AC energy readings, we can determine the efficiency of the off-grid system, which is affected by the efficiency of energy conversion by the inverter and batteries.

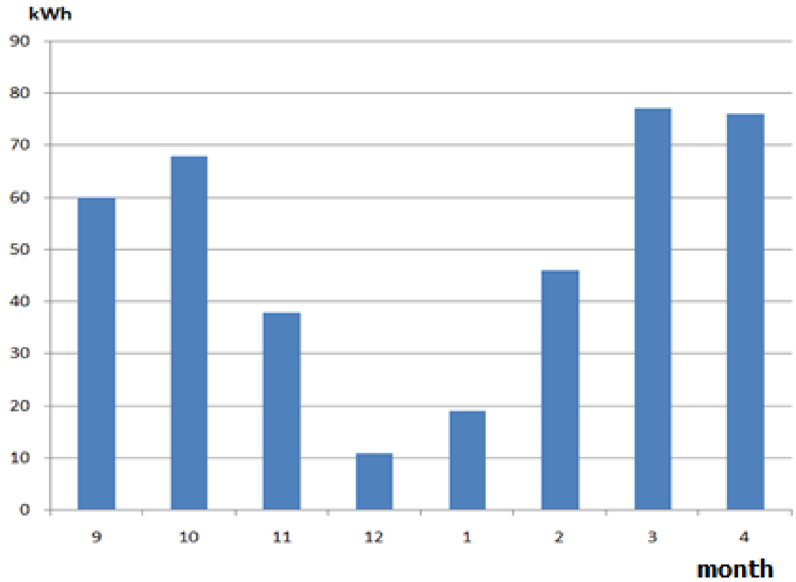

Figure 7. AC power taken from the off-grid system over an eight-month period (months: September to April).
Source: own elaboration.

The total energy for the off-grid system on the DC side (provided from the modules) is 659 kWh and for the AC side 395 kWh.

Off-grid system efficiency:

$$\eta = \frac{E_{DC}}{E_{AC}} = \frac{395}{661} = 0.6$$

4.2. Research of electrical parameters of batteries

The set of the off-grid system includes an energy storage built of batteries made in acid technology, therefore it is very important to check the batteries in terms of the basic parameter, which is the ability to accumulate electricity (Babu et al., 2020; Dascalua, Sharkha, Crudena, Stevenson, 2022; Dehghani-Sanij, Tharumalingam, Dusseault, Fraser, 2019; Hemmati, Saboori, 2016; Koohi-Fayegh, Rosen, 2020; Maleczek, Szczepaniak, Radek, Kowalkowski, Bogdanowicz, 2022). The batteries (AGM technology) under study were charged to full capacity in each cycle at room temperature (T=25°C). The tests were performed using an artificial load (Figure 8). The tested batteries were discharged with a standard ten-hour current, i.e. 10 A (for a battery with a capacity of 100 Ah). The discharge process was carried out for three temperatures (-25°C, 25°C, +50°C) until the limit voltage of about 10.6 V was reached.

Figure 8. Technological load.
Source: own elaboration.

An example of the current-voltage characteristics of the discharge process of the tested battery for temperature is shown in Figure 9.

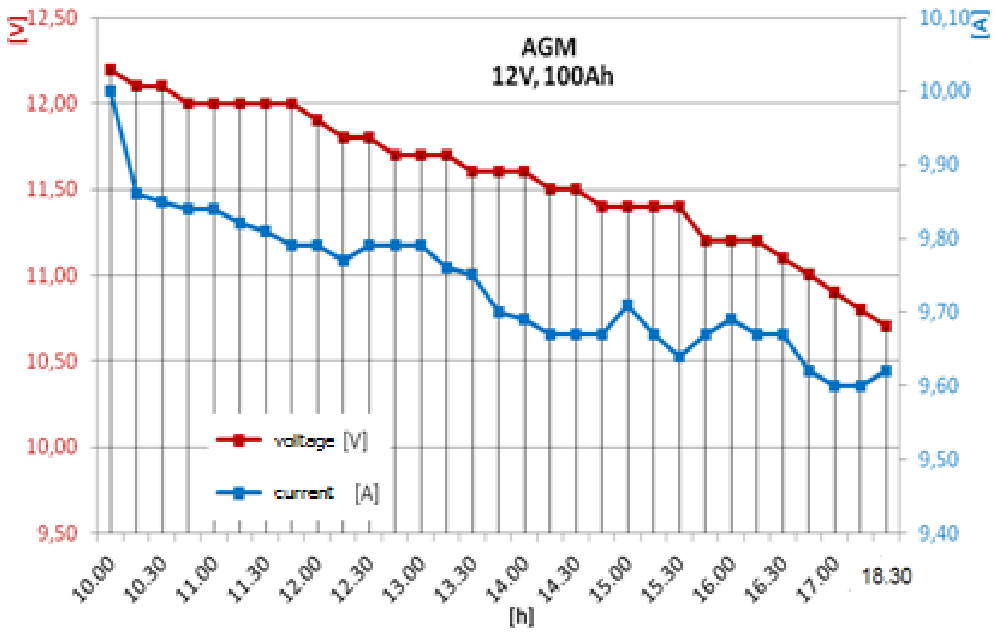

Figure 9. Battery voltage and discharge current characteristics for T= +50°C.
Source: own elaboration.

The results of the accumulated energy read from the artificial load are presented in table 1.

Table 1
Summary of measurement results

Temperature	-20°C	+25°C	+50°C
Energy [kWh]	0.64	1.26	0.97

Source: own elaboration.

4.3. Wind turbine research

During the use of the complementary energy system, the idea of using a wind turbine as an additional source of energy was born. Preliminary research was carried out before attempting to use it. The subject of the research was a light, not large-sized, 300W wind farm with additional protection against too strong wind by twisting the tail (Figure 10). Thanks to the 6-blade propellers, a faster start of charging the energy storage is ensured. The tests were carried out at ambient temperature (T=20°C). and the measuring set included the following equipment:

- a device for measuring wind speed;
- ammeter and voltmeter – universal instruments;
- load – adjustable resistor;
- temperature meter.

Figure 10. Wind turbine mounted on a test stand.
Source: own source.

The wind turbine was mounted at a height of approx. 3 m above ground level, on a special tripod. While the wind was blowing, its speed and current and voltage in the tested measuring circuit were read (Figure 11). Readings were made many times due to changing wind conditions. Average values were taken as measurement results (Table 2).

Table 2
Summary of measurement results

Wind speed [m/s]	2.1	4.3	6	10	12	15.3	20
Circuit voltage [V]	0	20.5	22.3	25.1	26.0	27.1	28.2
Current [A]	0	0.9	1.9	2.9	3.9	5.6	8.9
Current power [W]		18.45	42.37	72.8	101.4	151.76	250.98

Source: own elaboration.

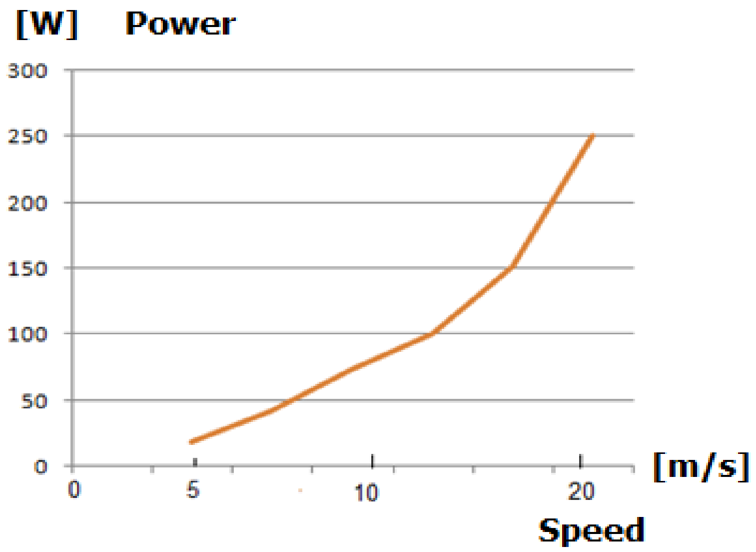

Figure 11. Power characteristics as a function of wind speed.
Source: own elaboration.

4.4. The influence of snow

In the winter period of using the system, the impact of the snow layer on the surface of the photovoltaic module on the production of electricity was checked (Figure 12). The study was to confirm one of the reasons for mounting solar modules at ground level.

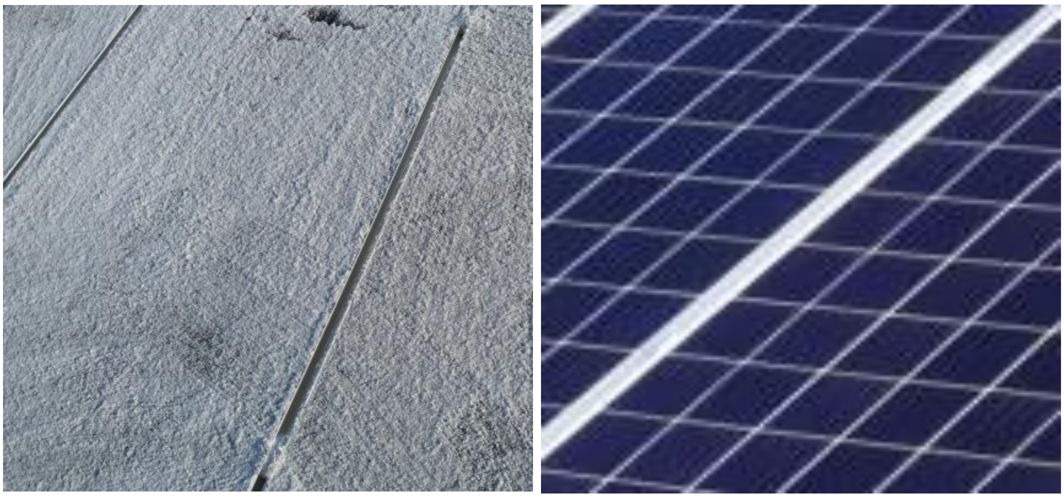

Figure 12. View of the module surface covered with snow after partial (left) and complete snow removal (right).
Source: own source.

The obtained results are presented in Table 3.

Table 3
Summary of measurement results

Snow layer thickness [cm]	Power [W]
0	1,300
0,5	440

Source: own elaboration.

5. Conclusions

The results of the research and the operational and cost indicators achieved confirm the validity of the solution in which, apart from generation and self-consumption, attention was paid to the importance of having a prosumer's own energy storage ensuring energy security during interruptions in energy supply from the operator. The obtained results in terms of the energy balance fully meet the adopted assumptions regarding self-consumption. This is confirmed by the settlements received from the energy operator, which include only fixed charges. On average (three-year observations) about 350 kWh remain available for the next period, which is about 5% of the annual production of the system. Such a good result was achieved thanks to the proper selection of heating systems. Fees for gas fuel and firewood do not exceed PLN 100 per month. For comparison, a similar house heated with pellets costs about PLN 5,000 zloty. Tests of batteries (acid AGM technology) confirmed their full suitability for home systems. Batteries are much cheaper and safer, and with not too deep discharge, they ensure long storage life. Of course, this is paid for by larger dimensions and weight, but in the case of a home stationary warehouse, it should not matter. Attempts to use a wind turbine have failed. Unstable operation, low efficiency as well as noise and the risk of an accident (possible damage to the propeller) basically preclude its use in a single-family house. Another important aspect to consider is the installation location of the photovoltaic modules. Based on the results of the analyses, it seems that the best solution (apart from the aesthetics and "loss" of the garden area) is to install the modules on the ground. This solution has the following advantages; easy access of modules in the event of a failure or the need to clear snow, lower operating temperature which improves energy efficiency and greater safety in the event of a fire. Studies of the impact of snow cover show that even 0.5 cm of snow causes a three-fold decrease in power. Very important premises for the construction of a complementary system are: its high reliability (two separate inverters and air conditioners not connected with gas heating), having an energy storage (storing part of surplus energy, relieving the energy system) and, most importantly, working as a UPS supplying energy to sensitive receivers ensuring their uninterrupted work.

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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

The impact of damage and technical condition of railway vehicles on railway transport safety in Poland

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Abstract: Railway vehicles are an integral part of the railway system. Therefore their failures may lead to dangerous events in the context of the safety of the entire railway system in Poland. For the purposes of the article, an analysis of railway incidents in Poland was carried out from 2015 to 2020, based on data published by the State Commission for the Investigation of Railway Accidents (PKBWK) and the Office of Rail Transport (UTK). The statistical analysis included events divided into "serious accidents", "accidents" and "incidents", the definitions and categorisation of which are presented in the Regulation of the Minister of Infrastructure and Construction of 16 March 2016 on serious accidents, accidents and incidents in rail transport. Within each of the groups of events, the most common categories of causes of direct events were distinguished, and then events whose direct cause had their origin in the poor technical condition or failure of rail vehicles were distinguished. The conducted analyses cover railway vehicles and do not include metro and tramway rolling stock. During the analysed period, no "serious accident" was recorded, the direct cause of which was related to the technical condition of rail vehicles, but in the group of events "accidents", and in particular "incidents", the share of events of this category is significant (from a few to several dozen per cent of all events). The level of detail of data published by the State Commission for the Investigation of Railway Accidents or the Office of Rail Transport does not allow the assessment of which particular technical system of a railway vehicle is most frequently subject to failure (detailed reports are published only for "serious accident" events). Therefore, in order to comprehensively assess the impact of technical failures of railway vehicles on the safety of rail transport in Poland, it is recommended to conduct more detailed analyses in cooperation with the Commission or the Office of Rail Transport.
Key words: safety, breakdowns, failure, railway vehicles, railway transport, open risk valuation, accident, serious accident, incident.

1. Introduction

European railways remain among the safest in the world. The number of serious rail accidents has been steadily decreasing in recent years. The basic indicator for the number of fatalities per 1 billion passenger-kilometres for railways is 0.058 and is the same as the value of the indicator for aviation. Its value is also 44 times lower than for individual car transport and almost four times lower than for coach transport [1]. Analysing the indicator determining the number of fatalities per 1 million vehicle-kilometers, there are large, at least 10-fold discrepancies between the EU countries with the lowest rates and those with the highest rates. In both cases, the median values are significantly lower than the average values because the indicators for EU countries with relatively high ratios are much higher than those for other countries. As for the mortality rate, a group of 11 high-value countries is emerging, which clearly contrasts with the values for the other EU Member States. Poland is in the group of these countries.

Unlike the European aviation and maritime industry, railways have still not implemented an EU-wide system for reporting rail safety incidents. This would allow conclusions to be drawn, leading to appropriate preventive and risk mitigation actions. This system should include reporting information not only on serious rail accidents, but also on incidents or potentially hazardous situations – thus, events without fatalities. The European Union Agency for Railways proposes to use a safety assessment method consisting of two elements for assessing railway safety:

1) Mandatory reporting of railway traffic safety incidents in order to learn about the mechanisms and scenarios that may lead to accidents and serious accidents.
2) Introducing the notion of dimension/level of safety by defining the rank of the ability of the carrier/ECM to manage the risk control measures put in place to control the risks associated with its activities. This will allow for assessing the adequacy of the entity's approach to risk management in this area.

In order to achieve the above objectives, it will be necessary, as in aviation, to create a common platform dedicated to the exchange and collection of information and data on railway traffic safety violations.

2. Purpose of work, classification of accident events

In this work, a statistical analysis of railway incidents in Poland in the years 2015-2020 was carried out. The analysis was carried out, among others, on the basis of data published in the annual reports of the National Commission for the Investigation of Railway Accidents (PKBWK) (PKBWK, 2015, 2016, 2017, 2018, 2019, 2020) and on the basis of data published by the Office of Rail Transport (UTK) in the reports on the state of railway traffic safety (Office for Railroad Transport, 2020; Office for Railroad Transport, 2020) and on the website of the Office (Office for Railroad Transport, 2023).

The aim of the work is to assess the impact of technical failures of rail vehicles on rail transport safety in Poland. The conclusions from the work can be used in the process of estimating and valuing the open risk, in accordance with EU Regulation 402/2013 (European Commission, 2013), in relation to changes in the technical systems of rail vehicles.

Railway safety violation events were analysed according to one of the categories – serious accident, accident, incident. Whenever a serious accident, accident or incident is referred to, the definitions indicated below, which originate from the Ordinance of the Minister of Infrastructure and Construction of 16 March 2016 (Minister of Infrastructure and Construction, 2016) on serious accidents, accidents and incidents in rail transport and the Instruction on proceedings in matters of serious accidents, accidents and incidents in rail transport Ir-8 (PKP Polskie Linie Kolejowe S.A, 2016), which takes into account the issues contained in Regulation of the Minister of Infrastructure and Construction of 16 March 2016 and is at the same time an act referred to in the PKP PLK Network Regulations (PKP Polskie Linie Kolejowe S.A., 2021), shall apply.

serious accident – any accident caused by a collision, derailment or another occurrence clearly affecting railway safety regulations or safety management:

(a) with at least one fatality or at least five seriously injured persons;

(b) causing significant damage to the railway vehicle, infrastructure or environment, which the accident investigation board can immediately estimate to be at least EUR 2 million.

accident – an unintended emergency event or a sequence of such events involving a railway vehicle, causing negative consequences for human health, property or the environment; accidents include in particular:

a) collisions;
b) derailments;
c) events at crossings;
d) events involving persons caused by a railway vehicle in motion;
e) fire of a railway vehicle.

incident – any event, other than an accident or serious accident, affecting the safety of railway traffic.

Individual events were also assigned an appropriate qualification of direct causes. For accidents (B) and major accidents (A), the qualification of direct causes according to Table 1 shall apply. Table 2 applies to incidents.

For serious accidents and accidents whose direct cause is a consequence of the inadequate technical condition of the rolling stock, the event categories A10, A11, A37 and B10, B11, B37 apply, i.e. damage or poor technical condition of the railway vehicle with propulsion, special purpose railway vehicle and damage or poor technical condition of the wagon, respectively.

Table 1
Qualification of the direct cause of a serious accident (A) or accident (B) and its categories

No.	Direct cause qualification	*Category
1	Causes other than those listed below or overlapping of several causes at the same time, creating equivalent causes	00
2	Setting the railway vehicle on a busy, closed track or the track in the opposite direction or in the wrong direction	01
3	Acceptance of a railway vehicle at a station on a closed or busy track	02
4	Setting, acceptance or running of a railway vehicle on an improperly arranged unprotected route or improper operation of railway traffic control devices	03
5	Failure to stop the railway vehicle before the 'Stop' signal or at a place where it should stop, or starting the railway vehicle without the required authorisation	04
6	Failure to exercise caution after the railway vehicle has passed an automatic standstill signal or a doubtful signal after stopping in front of these signals	05
7	Exceeding the maximum authorised driving speed	06
8	Execution of a maneuver posing a threat to the safety of train traffic	07
9	Derailment of a railway vehicle	08
10	Damage or poor maintenance of a structure, e.g. permanent way, bridge or overpass, including improper performance of works, e.g. improper unloading of materials, surface, leaving materials and equipment (including road machinery) on the track or in the gauge of the railway vehicle or overrunning the railway vehicle on the elements of the structure	09
11	Damage or poor technical condition of a railway vehicle with propulsion, special purpose railway vehicle (including overrunning of the item constituting the structural part of the railway vehicle with propulsion, special purpose railway vehicle) and damage or malfunction of the on-board part of the control-command and signalling devices (ERTMS)	10
12	Damage or poor technical condition of the wagon (including overrun on the structural part of the wagon)	11

13	Damage or malfunction of railway traffic control devices	12
14	Running a railway vehicle over a railway vehicle or another obstacle (e.g. brake skid, luggage trolley, mail cart)	13
15	Criminal assassination	14
16	Misalignment of the switch under the railway vehicle	15
17	Incorrect train or shunting trainset composition	16
18	Improper loading, unloading, failure to secure the load or other irregularities in the loading operations or improper train or shunting trainset composition	17
19	Collision of a railway vehicle with a road vehicle (other road machinery, agricultural machinery) or vice versa at a level crossing with turnpikes (category A according to the crossing metric)	18
20	Collision of a railway vehicle with a road vehicle (other road machinery, agricultural machinery) or vice versa at a level crossing equipped with an automatic crossing system with traffic lights and turnpikes (cat. B)	19
21	Collision of a railway vehicle with a road vehicle (other road machinery, agricultural machinery) or vice versa at a level crossing equipped with an automatic crossing system with traffic lights and without turnpikes (cat. C)	20
22	Collision of a railway vehicle with a road vehicle (other road machinery, agricultural machinery) or vice versa at a level crossing not equipped with a level crossing system (cat. D)	21
23	Collision of a railway vehicle with a road vehicle (other road machinery, agricultural machinery) or vice versa at a level crossing for private use (cat. F)	22
24	Rolling a railway vehicle onto a road vehicle (other road machinery, agricultural machinery) or vice versa outside rail-road crossings at stations and routes or on the communication and access track to the sidetrack	23
25	Fire on a train, shunting trainset or on a railway vehicle	24
26	Fire in a building structure, etc., within the railway area, forest fire within the limits to the end of the fire lane, fire of cereals, grasses and tracks occurred within the railway area	26
27	Explosion on a train, shunting trainset or railway vehicle	27
28	Natural disasters (e.g. floods, snowdrifts, ice blocks, hurricanes, landslides)	28
29	Construction disasters in the immediate vicinity of railway tracks on which normal train movements take place	29
30	Malicious, hooligan or reckless misdeeds (e.g. throwing stones at a train, stealing cargo from a train or shunting trainset in motion, laying an obstacle on the track, devastating power, communications and railway traffic control equipment or permanent way infrastructure and interfering with this infrastructure)	30
31	Railway vehicle collision with persons while crossing the tracks at a rail-road crossing or a guarded crossing	31
32	Railway vehicle collision with persons while crossing the tracks at a rail-road crossing with an automatic crossing system (cat. B, C)	32
33	Railway vehicle collision with persons while crossing the tracks at other rail-road crossings and walkways	33
34	Railway vehicle collision with persons while crossing tracks outside rail-road crossings or walkways at stations and routes	34

35	Events involving persons related to the movement of the railway vehicle (jumping, falling off the train, railway vehicle, strong approach or sudden braking of the railway vehicle)	35
36	Ignoring signals prohibiting entry to the level crossing by the road vehicle operator and damage to the turnpike or traffic signals	36
37	Train or shunting trainset break-up resulting in runaway wagons	37
38	Incorrect operation of structures and equipment intended for railway traffic control or incorrect operation of railway vehicles caused by theft	38
39	Entry of a railway vehicle using traction energy from the overhead contact line into an unoccupied non-electrified track	39
40	Uncontrolled release of dangerous goods from the wagon or packaging requiring the intervention of authorities or the use of measures to eliminate fire, chemical, and biological hazards at the station or on the route	40

Source: Regulation of the Minister of Infrastructure and Construction of 16 March 2016 on serious accidents, accidents and incidents in rail transport, Minister of Infrastructure and Construction, 2016, Warszawa: Jurnal of Laws of 2016, ithem 369, retrieved from: https://isap.sejm.gov. pl/isap.nsf/DocDetails. xsp?id=WDU20160000369 (access: 10.05.2023).

Table 2
Qualification of the direct cause of the incident and its categories

No.	Direct cause qualification	*Category
1	Setting the railway vehicle on a busy, closed track or the track in the opposite direction or in the wrong direction	C41
2	Acceptance of a railway vehicle at a station on a closed or busy track	C42
3	Setting, acceptance or running of a railway vehicle on an improperly arranged unprotected route or improper operation of railway traffic control devices	C43
4	Failure to stop the railway vehicle before the 'Stop' signal or at a place where it should stop, or starting the railway vehicle without the required authorisation	C44
5	Exceeding the maximum authorised driving speed	C45
6	Execution of a maneuver posing a threat to the safety of train traffic	C46
7	Derailment of a railway vehicle	C47
8	Misalignment of the switch under the railway vehicle	C48
9	Incorrect train composition	C49
10	Improper loading, unloading, failure to secure the load or other irregularities in the loading operations	C50
11	Damage to the permanent way, bridge or overpass, overhead contact line, also improper performance of works, e.g. improper unloading of materials, leaving materials and equipment (including road machinery) on the track or in the gauge of the railway vehicle	C51
12	Incorrect operation of railway traffic control devices causing: – failure to cover the line blocking distance occupied by the railway vehicle with the "Stop" signal, – setting of the permitting signal on the semaphore with improperly arranged route, improper operation of track or turnout vacancy devices, improper operation of station or line blocking devices, – failure to warn and protect road users from a train approaching a level crossingor a crossing equipped with a level crossing system	C52

13	Damage to or poor technical condition of the railway vehicle with propulsion, special purpose railway vehicle making it necessary to put it out of service as a result of indications by rolling stock malfunction detection equipment, confirmed in workshop conditions (hot axle boxes, hot brake resulting in a displaced rim), as well as other faults in railway vehicles in motion noticed by the service personnel (e.g. broken spring)	C53
14	Damage to or poor technical condition of the wagon making it necessary to put it out of service as a result of indications by rolling stock malfunction detection equipment, confirmed in workshop conditions (hot axle boxes, hot brake resulting in a displaced rim), as well as other faults in railway vehicles in motion noticed by the service personnel	C54
15	Fire on a train or on a railway vehicle with no adverse effects on property or the environment, without victims	C55
16	Fire of the building structure and vegetation in the immediate vicinity of the railway tracks on which normal railway traffic takes place	C57
17	Uncontrolled release of dangerous goods from the wagon or packaging requiring the intervention of authorities or the use of measures to eliminate fire, chemical, and biological hazards at the station or on the route	C59
18	Railway vehicle running into an obstacle (e.g. brake skid, luggage trolley, mail cart, etc.) without derailment or casualties	C60
19	Criminal assassination	C61
20	Natural disasters (e.g. floods, snowdrifts, ice blocks, hurricanes, landslides)	C62
21	Construction disasters in the immediate vicinity of railway tracks on which normal train movements take place	C63
22	Malicious, hooligan or reckless misdemeanours (e.g. throwing stones at a train, stealing cargo from a train or shunting trainset in motion, laying an obstacle on the track, devastating power, communications, and railway traffic control equipment or permanent way infrastructure and interfering with this infrastructure), without casualties or negative consequences for property or the environment, posing a threat to passengers or train staff	C64
23	Events involving persons related to the movement of the railway vehicle (crossing tracks at level crossings and walkways on the route, jumping, falling off a train or a railway vehicle, collision with rolling stock in motion, heavy access to or rapid braking of a railway vehicle), without any damage or negative consequences for property or the environment	C65
24	Failure to stop the road vehicle in front of a closed turnpike (semi-turnpike) and damage to the turnpike or traffic signals on which signals were activated to warn of an oncoming train, without collision with the railway vehicle	C66
25	Incorrect operation of structures and equipment intended for railway traffic control or incorrect operation of railway vehicles caused by theft	C67
26	Train or shunting trainset break-up resulting in runaway wagons	C68
27	Causes other than those listed below or overlapping of several causes at the same time, creating equivalent causes	C69

Source: Regulation of the Minister of Infrastructure and Construction of 16 March 2016 on serious accidents, accidents and incidents in rail transport, Minister of Infrastructure and Construction, 2016, Warszawa: Jurnal of Laws of 2016, ithem 369, retrieved from: https://isap.sejm.gov. pl/isap.nsf/DocDetails. xsp?id=WDU20160000369 (access: 10.05.2023).

For incidents, the direct cause of which is due to the inadequate technical condition of the railway vehicles, the categories of events C53 and C54 and C68 apply, i.e. damage or poor technical condition of the railway vehicle with propulsion, special purpose railway vehicle and damage or poor technical condition of the wagon, respectively.

3. Analysis of railway events in Poland

In the years 2015-2020, a total of 24 serious accidents were recorded in Poland. The most common direct cause of events of this type was the rolling of a railway vehicle onto a road vehicle or, conversely, at level crossings of various categories. This group of events includes events categorised according to Table 1 as A18, A19, A20, A21, A22 and in the analysed period they accounted for over 83% of all serious accidents in Poland.

During the analysed period, no serious accident occurred, the direct cause of which would be the poor technical condition of the railway vehicle. A detailed list of serious accidents is shown in Figure 1.

"B" category events constituted a very large group of all events that were recorded in rail transport in Poland. In the years 2015-2020, there were a total of 3915 events, the largest group of which were accidents caused directly by the rolling of a railway vehicle on people when crossing tracks outside railway crossings or walkways at stations and routes (B34) – a total of 1075 events. In the second place in terms of the number of events, accidents were caused directly by the rolling of a railway vehicle onto a road vehicle or vice versa at a level crossing without a level crossing system (B21) – a total of 780 events. The third group consisted of events directly caused by damage or poor maintenance of the structure, including the improper performance of works (B09) – a total of 292 events. Only three categories of events, i.e. B34, B21 and B09 accounted for 54.8% of all events between 2015 and 2020. Figure 2 presents a detailed analysis of the frequency of occurrence of individual categories of events.

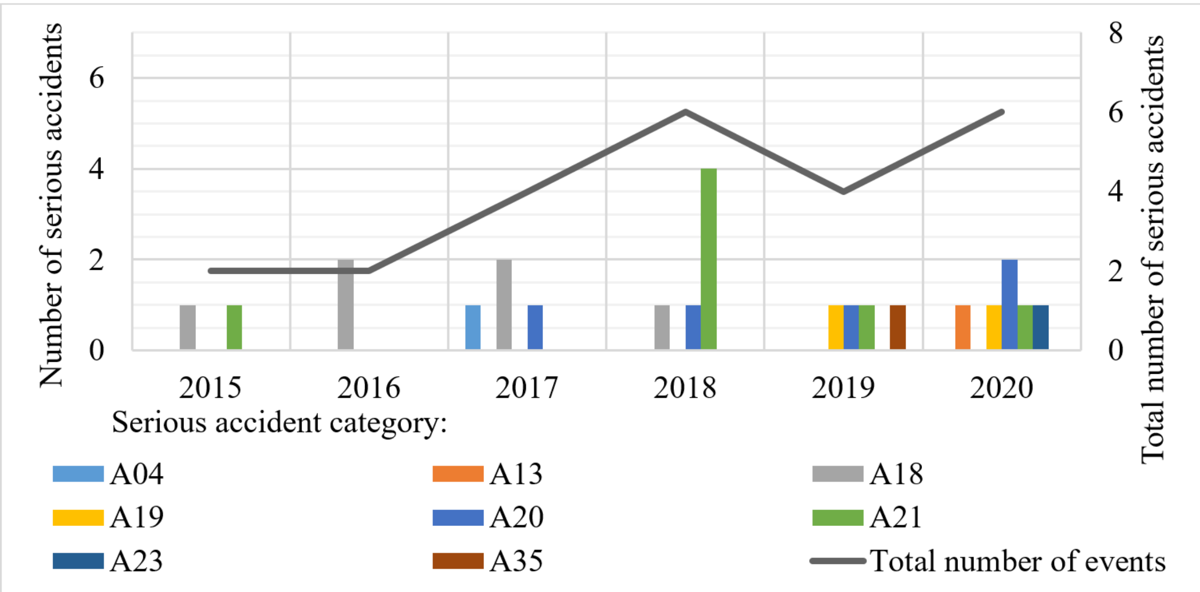

Figure 1. List of serious accidents in Poland in 2015-2020.
Source: own study based on the (PKBWK, 2015, 2016, 2017, 2018, 2019, 2020).

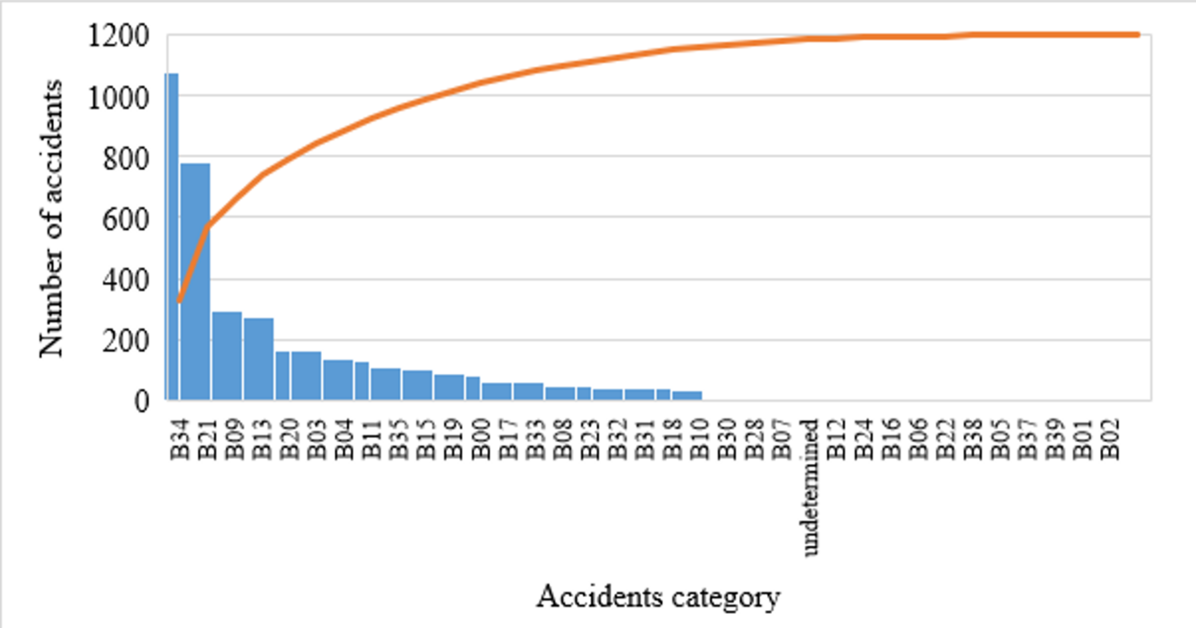

Figure 2. Pareto diagram for accidents in Poland in 2015-2020.
Source: own study based on the (PKBWK, 2015, 2016, 2017, 2018, 2019, 2020).

Analysing the number of events of all categories in individual years, it can be concluded that since 2017 the number of such events has been systematically decreasing. Also in relation to the three categories of events discussed above, i.e. B34, B21 and B09, there has been a clear downward trend, which is a very positive phenomenon from the point of view of railway transport safety. The quantitative summary of all events in the years 2015-2020, including the analysis of trends, is presented in Figure 3.

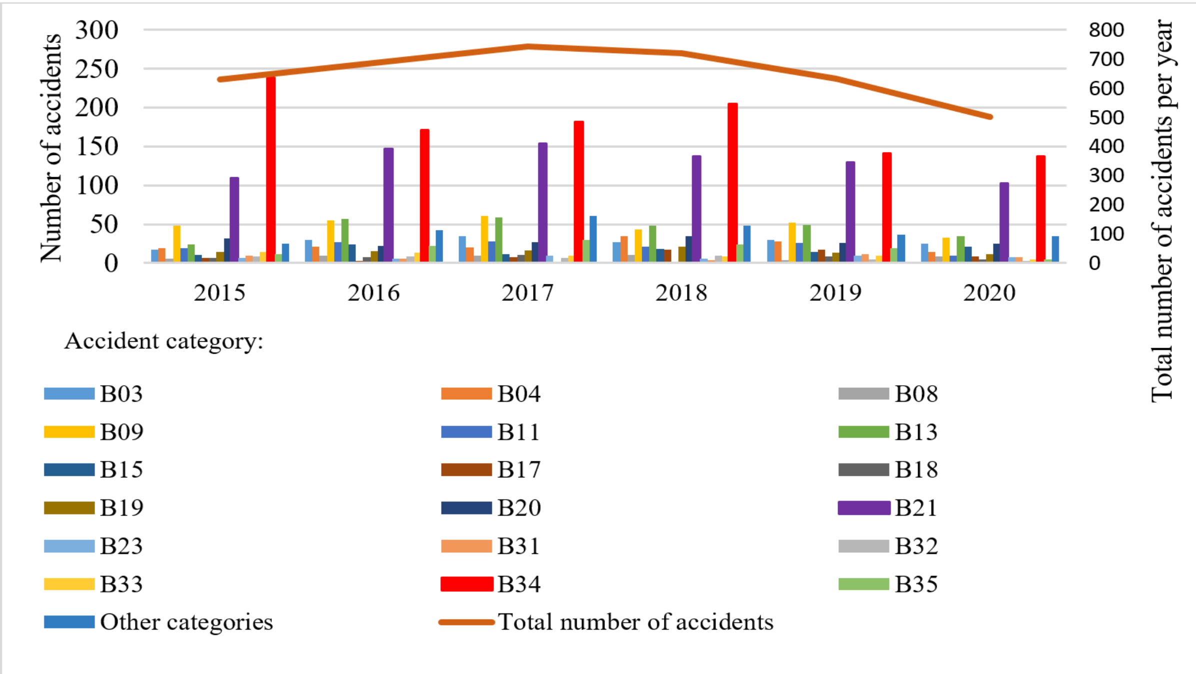

Figure 3. List of serious accidents in Poland in 2015-2020.
Source: own study based on the (PKBWK, 2015, 2016, 2017, 2018, 2019, 2020).

From the point of view of the impact of technical failures of rolling stock on the number of dangerous accidents of the type of accidents, the most important events are those of category B10, the direct cause of which is damage or poor technical condition of the railway vehicle with propulsion or special purpose railway vehicle, and those of category B11, the direct cause of which is damage or poor technical condition of the wagon.

Accidents of categories B10 and B11 accounted for 4.2% of all accidents in the analysed period. Most of the accidents that have been assigned to the condition of the rolling stock relate to the condition of the wagons.

In the group of events classified as incidents, of which a total of 6414 were recorded in the analysed period, there are events that are directly caused by the damage or poor technical condition of the wagon, causing the need to shut it down (C54). In 2015-2020, 1,456 incidents of this category were recorded. The second place was occupied by incidents directly caused by the breakdown of the train or shunting trainset, which did not cause the coincidence of wagons (C68) – a total of 1349 events. The third group consisted of incidents directly caused by malicious, hooligan or reckless misdemeanours (C64) – a total of 953 incidents. Figure 5 presents a detailed analysis of the frequency of occurrence of individual categories of incidents.

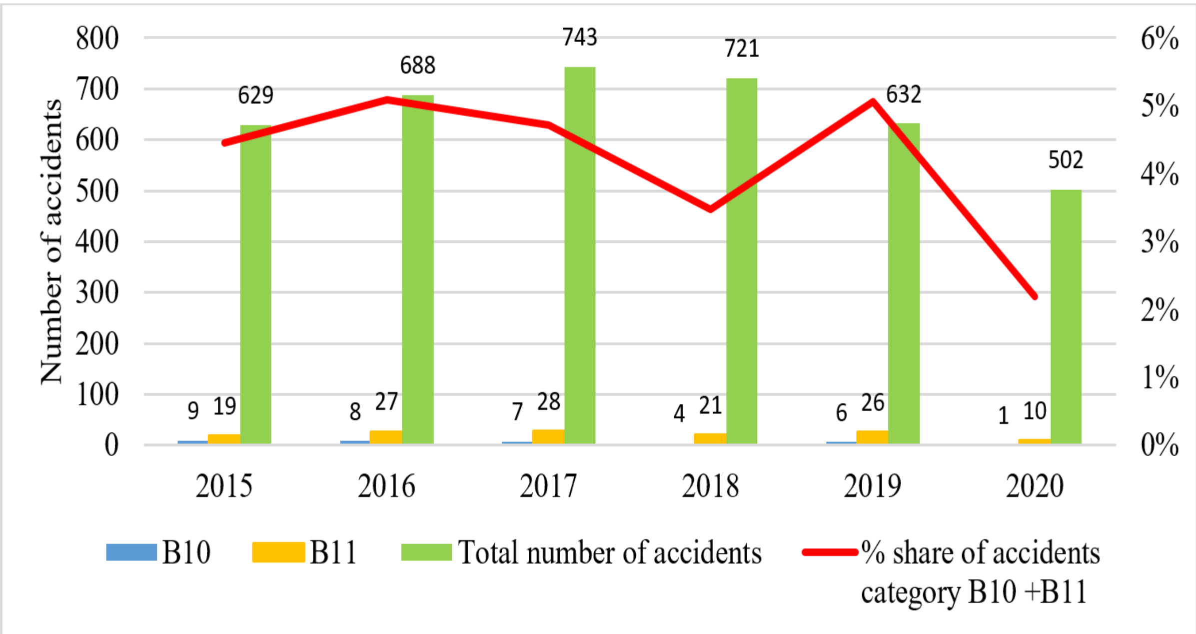

Figure 4. The share of category B10 and B11 accidents in relation to all accidents in Poland in the years 2015-2020.
Source: own study based on the (PKBWK, 2015, 2016, 2017, 2018, 2019, 2020).

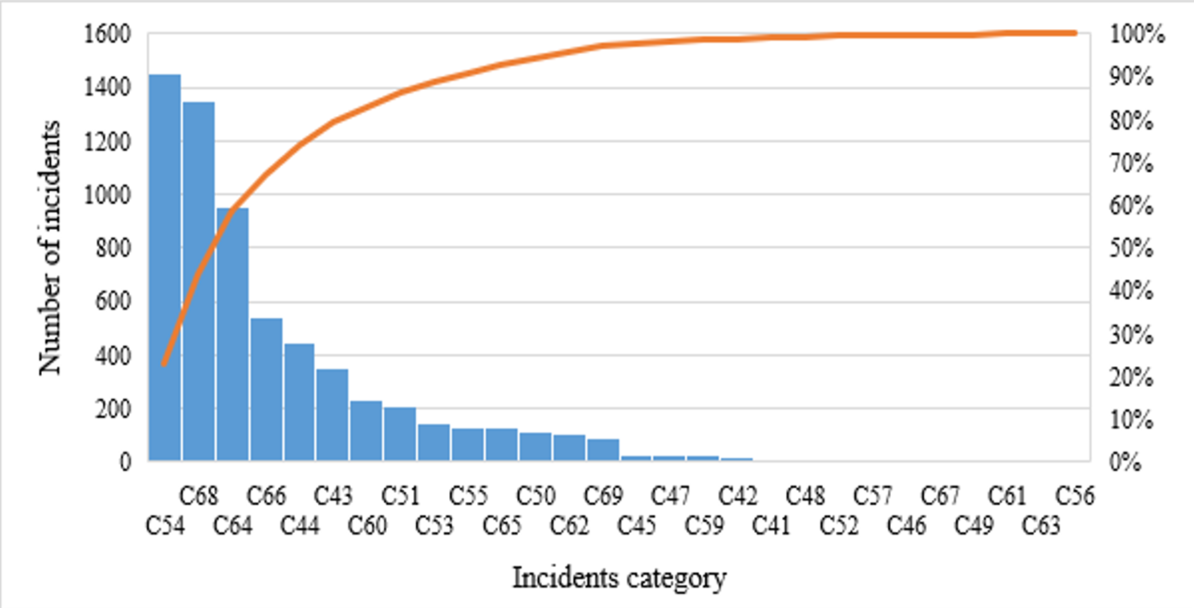

Figure 5. Pareto diagram for incidents in Poland in 2015-2020.
Source: own study based on the (PKBWK, 2015, 2016, 2017, 2018, 2019, 2020).

Between 2015 and 2017, the number of incidents increased sharply (521 incidents in 2015 versus 1270 in 2017). Since 2017, the number of incidents has remained almost unchanged, with around 1260 events per year. The number of incidents of the most common category, i.e. C54, has been steadily decreasing. In turn, during the analysed period, there was a sharp increase in the number of C64 category incidents. The quantitative summary of all inidents in the years 2015-2020, including the analysis of trends, is presented in Figure 6.

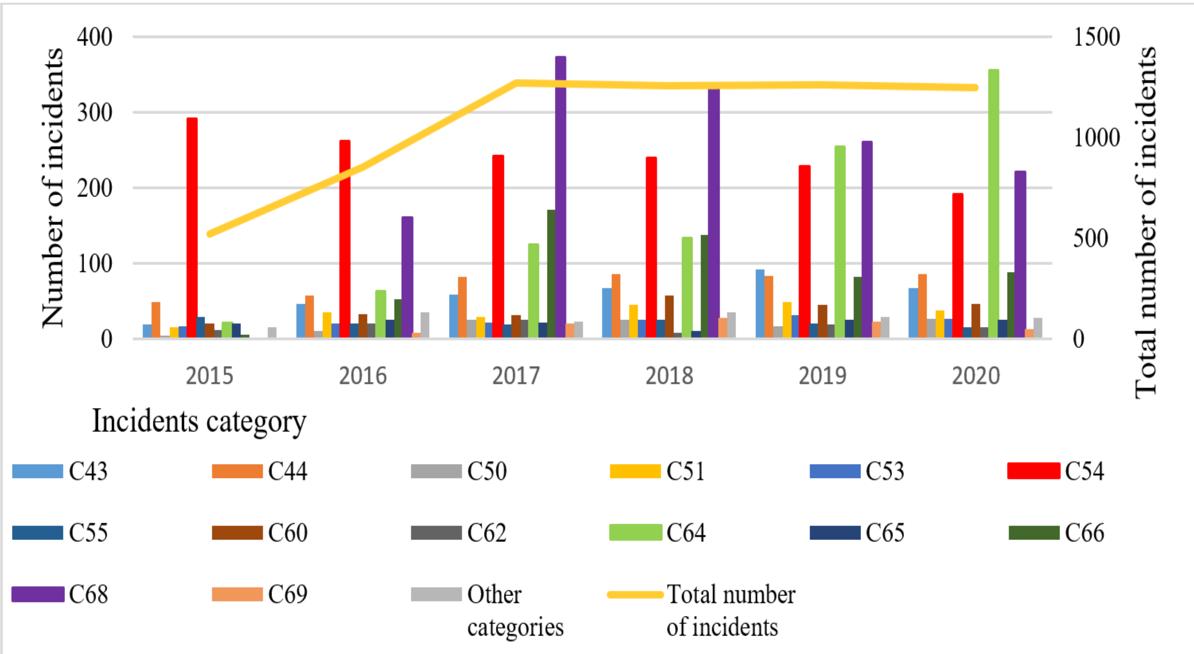

Figure 6. List of incidents in Poland in 2015-2020.
Source: own study based on the (PKBWK, 2015, 2016, 2017, 2018, 2019, 2020).

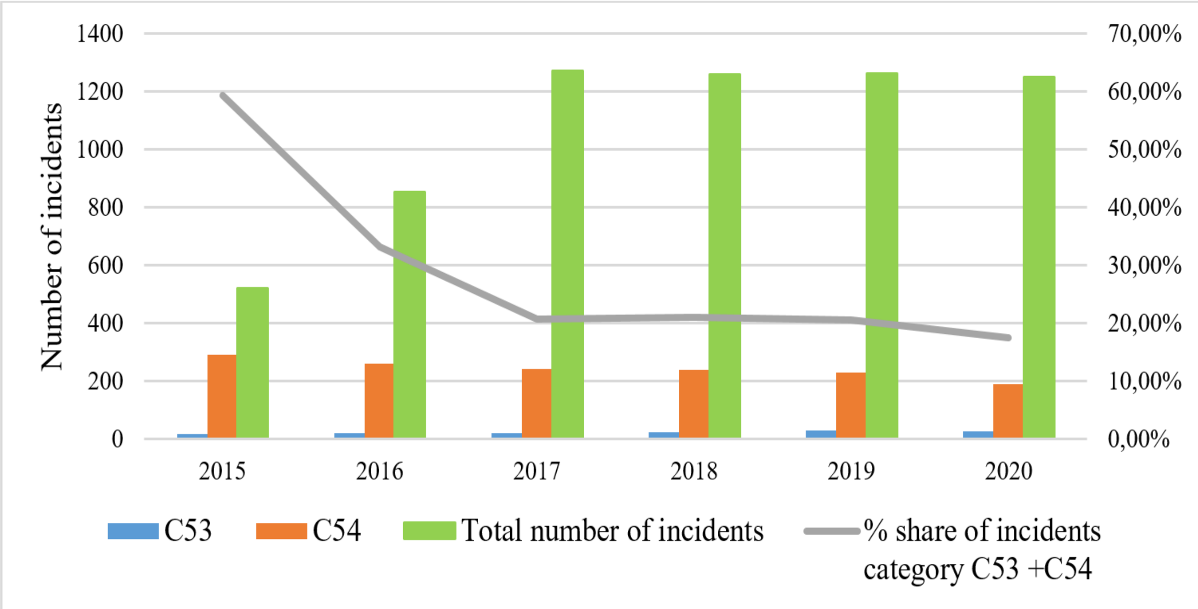

Figure 7. Incidents of categories C53 and C54 in relation to all incidents in Poland in the years 2015-2020.

Source: own study based on the (PKBWK, 2015, 2016, 2017, 2018, 2019, 2020).

The most important categories of incidents that can be directly related to the impact of rail vehicle failures on the safety of rail transport in Poland are categories C53 and C54. The data presented in Figure 7 indicate that the percentage of incidents originating in the rolling stock condition is systematically decreasing, with the largest decrease recorded in 2016 and 2017. However, when analysing the data, it should be taken into account that in 2017 the number of incidents in other categories increased significantly, which indirectly contributed to a sharp decrease in the percentage of events in categories C53 and C54 (a decrease from 59% in 2015 to 17.5% in 2020, i.e. by almost 42%). In fact, the number of incidents of these categories, without reference to the total number of all incidents) decreased by 30% when comparing data for 2015 and 2020.

4. Conclusions

During the analysed period, no serious accident occurred, the direct cause of which would be the poor technical condition of the railway vehicle. Accidents of categories B10 and B11 accounted for 4.2% of all accidents in the analysed period. Overall, from year to year (excluding 2019), the share of accidents classified as category B10 and B11 events in the overall number of accident events is decreasing. Most accidents caused by poor technical condition are related to events involving wagons.

The level of detail of data published by the State Commission for the Investigation of Railway Accidents or the Office of Rail Transport does not allow the assessment of which particular technical system of a railway vehicle is most frequently subject to failure (detailed reports are published only for "serious accident" events). Therefore, in order to comprehensively assess the impact of technical accidents of railway vehicles on the safety of rail transport in Poland, it is recommended to conduct more detailed analyses in cooperation with the Commission or the Office of Rail Transport.

Unlike the European aviation and maritime industry, railways have still not implemented an EU-wide system for reporting rail safety incidents. This would allow conclusions to be drawn, leading to appropriate preventive and risk mitigation actions. This system should include reporting information not only on serious rail accidents, but also on incidents or potentially hazardous situations – thus, events without fatalities. In order to achieve the above objectives, it will be necessary, as in aviation, to create a common platform dedicated to the exchange and collection of information and data on railway traffic safety violations.

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AGV autonomous vehicle in the structure of a car assembly line

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Abstract: The work of AGV (Automated Guided Vehicles) mobile robots is supervised by the IntraFleet system, which enables the design of logistics processes and traffic management, taking into account the infrastructure of the production hall. AGV robots move in a fixed route of magnetic tapes, optical or laser systems – using wireless communication, e.g. wi-fi or bluetooth. AGV routes intersect with each other, which makes it necessary to introduce a system that monitors the position of individual transport units. Based on the layout of the hall, a project was developed for a collision-free route for the AGV trolley connected to platforms intended for transporting elements of the car's cockpit, while maintaining synchronization with the time schedule of assembly operations at the line's stations.
Key words: AGV vehicle, RFID technology.

1. Introduction

The development of enterprises forces the modernization of transport systems in the production and storage areas. Along with new IT technologies, solutions have appeared that help to replace people in areas responsible for transport in production halls through the use of AGV (Automated Guided Vehicles) autonomous transport vehicles (River Systems 2022). Thanks to such solutions, the employee can be directed to other, more advanced activities. Industry 4.0 has become the main recipient of unmanned transport vehicles, which play an important role in the automation of production processes. The positioning of the passage of an autonomous vehicle is based on the use of magnetic tapes. Technological transport is carried out using various systems and supervision methods, depending on the needs and specificity of the production hall. The possibility of collision-free and safe movement of the vehicle around the production line zone within the hall is conditioned by the appropriate selection of a set of sensors responsible for safety (Puy, 2008).

The automotive industry in particular has benefited from the development of autonomous vehicles. Various types of autonomous transport trolleys are used in the car assembly halls. There is synchronization of the transport process of components with delivery to the appropriate position of the assembly line at a strictly defined time so as not to create warehouse zones. At this stage, there is no room for errors and the elimination of the human factor in the transport process ensures the continuity of the assembly lines. In most cases, the degree of synchronization of deliveries requires the use of many autonomous vehicles, which forces the planning of vehicle routes in a collision-free system. In addition, an autonomous vehicle must maintain adaptability to react in the event of obstacles appearing on the route. For this purpose, a number of sensors and protection devices are used that react quickly enough to slow down or stop the AGV (Baszuk, Szczęch, 2010).

Thus, the proposed modifications to the IT systems supervising the functioning of AGVs in the structure of the car assembly hall included in the publication constitute the next cognitive stage aimed at increasing the efficiency of the current system.

2. Methods

2.1. Determining the route of AGV trolleys

The collision-free route was designed based on the lay-out of the car assembly hall, where automated transport is carried out. Another important aspect is the conditions in a given part of the hall. At the beginning, communication routes in the area where the route is planned should be marked out. The main parameter is the width of the road, which must be sufficient to allow two vehicles to pass. In the analyzed case, an area of 3 m wide was designated for the communication zone at the narrowest point. Assuming that both vehicles are moving exactly in the center of their lane and taking into account their width, it is not possible for them to collide (Figure 1).

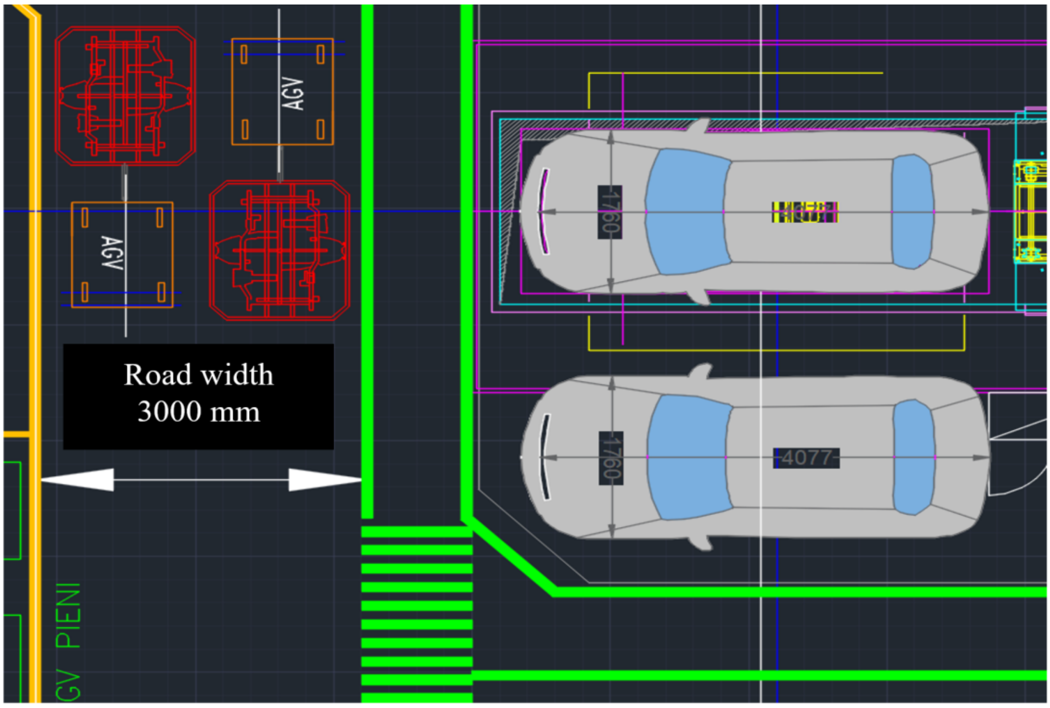

Figure 1. Position of AGV trolleys on the communication route of the car assembly hall (technological audit).
Source: own study based on a technological audit of the FCA car assembly hall.

To optimize the operation of the truck, it is recommended to choose a route based on the route about key aspects:

- route length;
- collision of the route with other AGV trucks;
- traffic volume on the road.

When transporting the car cockpit from the picking site to the assembly station, it is inevitable to cross the route of AGVs that operate within the hall (Figure 2). In the presented diagram, the existing route is combined with the route determining the transport of the cockpit. This solution simplifies the route and gives the opportunity to move along the same lines, thanks to which other road users will feel the presence of automated transport to a lesser extent.

Regardless of the chosen variant, the routes of vehicles intersect with each other, which makes it necessary to introduce a security system to prevent simultaneous approach of vehicles in collision areas. Then none of them will be able to continue driving and the route will be blocked (Choromański et al., 2020).

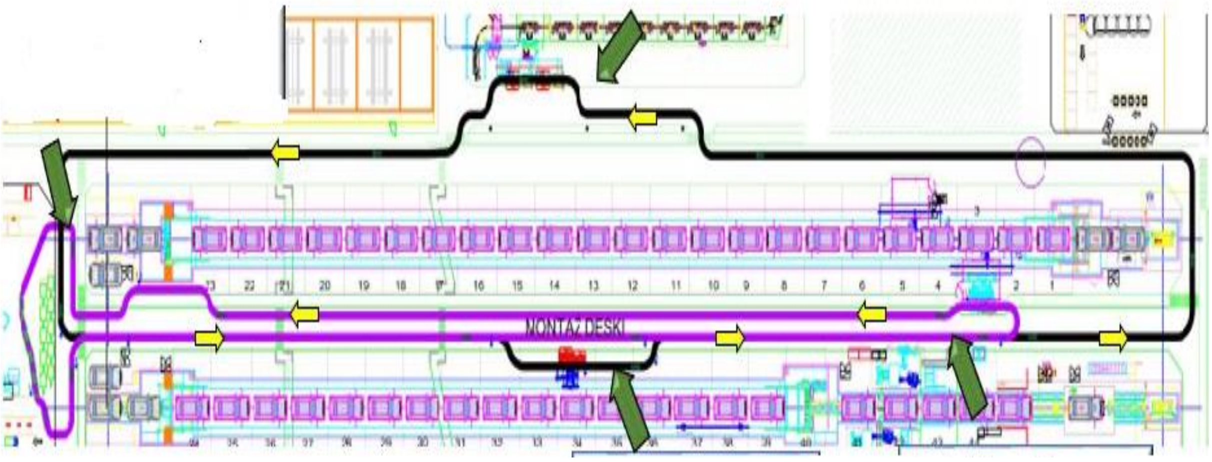

Figure 2. Lay-out of a fragment of a car assembly line with marked combined AGV routes (technological audit)
Source: own study based on a technological audit of the FCA car assembly hall.

2.2. Navigation method and vehicle fleet management system

When analyzing AGV control solutions available on the market, spatial control with the use of mapping of the environment is used more and more often. The use of navigation based on geolocation and avoiding obstacles in the assembly hall is difficult to implement and is not justified from the economic and reliability point of view. The construction of the hall and the high traffic of vehicles controlled by employees significantly disturb the autonomous operation of vehicles. When avoiding obstacles, the vehicle would have to reverse, which is impossible for multiple bogies. Trolleys connected by joints do not provide precise control when moving backwards. In the described example, AGVs use the magnetic tape method for navigation. Magnetic tapes are a durable and damage-resistant material that firmly adheres to a previously well-prepared substrate. Another advantage of the tapes is resistance to oil stains and other dirt. Tape-based navigation, thanks to its high resistance to a large amount of external light, dirt or condensate, works well in the presented case (Płaczek, Osieczko, 2020).

Navigation accuracy in this case reaches 1 mm. On the chassis of each trolley, there is a magnetic navigation sensor (Figure 3). This sensor is responsible for tracking the line on the floor, which determines the path of the River Systems 2022 vehicle). The sensor verifies the deviation of the vehicle in relation to the set position, which makes it possible to precisely set the AGV trolley in the line in relation to which it is to move (Puy, 2008). This sensor checks how far the trolley is from the center of the belt and then sends the information to the PLC via the IT bus. The controller, if necessary, corrects the position by changing the rotational speed of individual wheels. It is important that the sensor is located at a distance of about 30 mm from the floor of the hall.

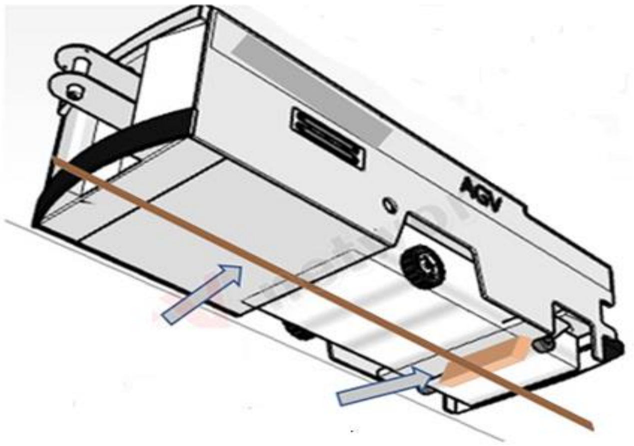

Figure 3. Location of the magnetic sensor.
Source: *What are automated quided vehicles?*, River Systems, 2022, retrieved from: https://6river.com (access: 10.05.2023).

During the passage of the AGV, the magnetic sensor placed on the vehicle must only supervise the set track. In case of encountering intersections and route junctions on your way, you need information on which route the trolley should choose. RFID technology was used for this purpose. It was proposed to install Siemens SIMATIC RF310R RFID readers on board autonomous vehicles (Figure 4). This compact size reader, mounted on the chassis of the AGV trolley, has a maximum range of 125 mm between the reader and the tag, which gives you the freedom to read tags glued to the floor. It communicates with the PLC via the PROFINET communication standard. Siemens 6GT2600 tags are placed on the floor in appropriate places. Their small dimensions and high strength guarantee proper operation. In addition, each marker is secured with a durable adhesive tape. This solution is very practical when heavy equipment enters the hall and there may be a risk of damage to the elements. Just peel off the markers and then stick them again in the same places. The RFID reader is located on the right side of the vehicle at a distance of 100 mm from the end of the magnetic sensor. Similarly, RFID tags glued on the right side of the tape at a distance of 100 mm from its edge.

Figure 4. SIEMENS RFID reader and tag.
Source: https://adegis.com (access: 10.05.2023).

The PLC program determines the orientation of the sensor to the right edge of the magnetic tape, thanks to which even in the case of a turnout and the appearance of two tape strips, the sensor will not misinterpret the track. Unless a message about changing the priority of the sensor readings is sent, the vehicle will always go to the right edge of the magnetic strip at the junctions. As a result, it will either continue straight ahead or turn right. Each position of the tape relative to the sensor is represented by a different numerical value, which is interpreted by the PLC to correct the position. The main assumption is that the vehicle should always move along the right edge and, in the case of a specific data frame contained in the tag, perform the operation assigned to it. Figure 5 shows a proposal for the location of RFID tags on the lay-out of the car assembly line, and Table 1 describes their functions.

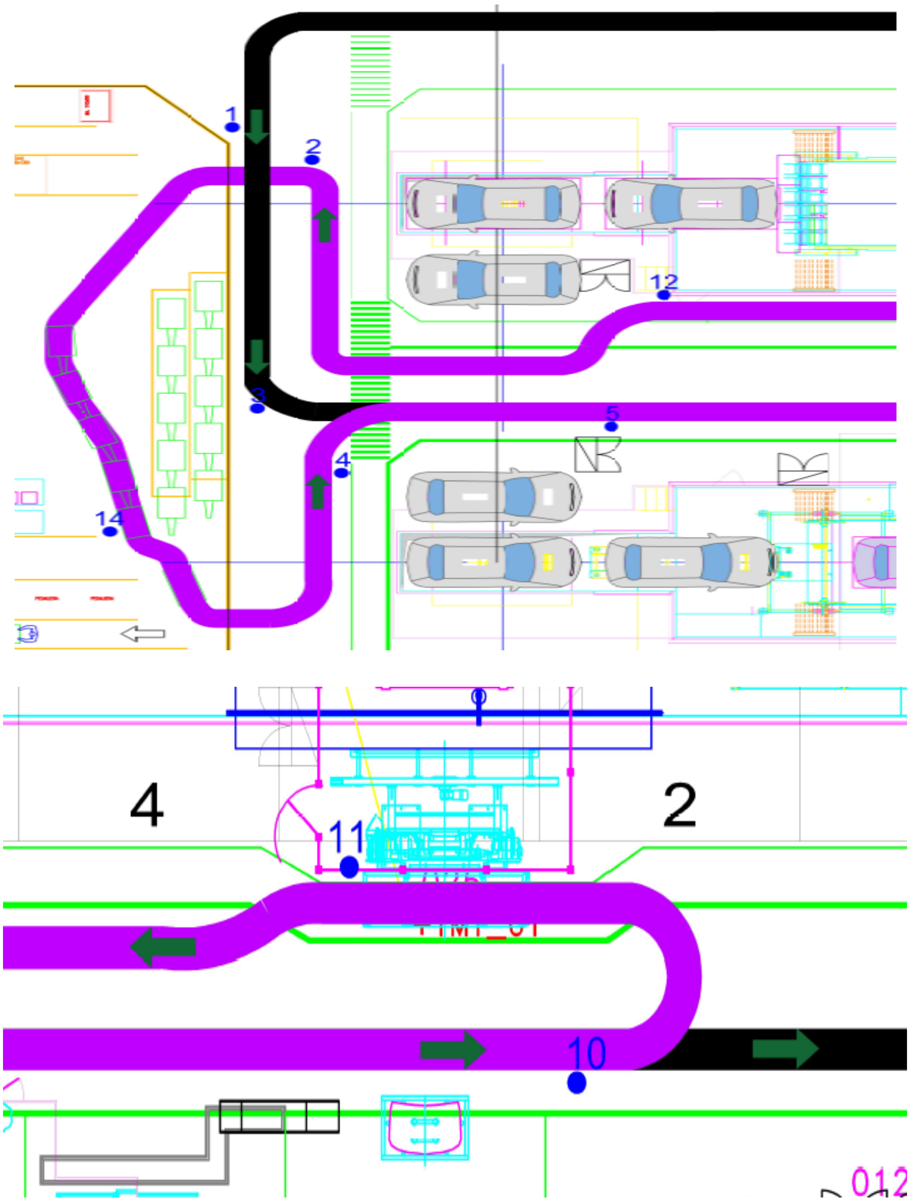

Figure 5. Location of RFID tags (technological audit).
Source: own study based on a technological audit of the FCA car assembly hall.

Thanks to RFID tags, the vehicle recognizes the given route and the control unit determines the position of the vehicles and issues a decision on their movement or the need to stop. RFID tags must be placed in the vicinity of each of the intersections and places where AGV transport routes connect. In order to effectively manage the movement of AGV trolleys in the hall, their mutual communication is necessary. For this purpose, each of the vehicles was equipped with the Anybus Wireless Bolt device (Figure 6). The module uses Bluetooth or Wi-Fi technology. It provides a range of up to 100 m and has an Ethernet connector through which it communicates with the PLC responsible for controlling the AGV.

Table 1
List of RFID tags used for the implementation of routes

Tag number	The analyzed AGV vehicle	Task
1	Transporting dashboards	Entering collision zone no.1, drive straight ahead
2	Transporting small items	Entering collision zone no.1, drive straight ahead
3	Transporting dashboards	Entering collision zone no.2, drive straight ahead
4	Transporting small items	Entering collision zone no.2
5	All	Leaving the collision zone
6	Transporting small items	Driving straight ahead
7	Transporting dashboards	Destination, Stop
8	Transporting dashboards	Entering collision zone no.3, drive straight ahead
9	Transporting small items	Entering collision zone no.3
10	Transporting small items	Turn left
11	Transporting small items	Destination, stop
12	Transporting small items	Collection of empty wagons, Stop
13	Transporting dashboards	Place of loading, stop
14	Transporting dashboards	Place of loading, stop

Source: own study based on a technological audit of the FCA car assembly hall.

Figure 6. Anybus wireless Bolt module.
Source: https://www.anybus.co (access: 10.05.2023).

Each of the trucks must be constantly within range of the wireless network in order to send and receive information about the other vehicles in motion. Devices in the network have a range of up to 100 m. Due to various obstacles that reduce the real area of operation, we assume an effective range of 75% of the maximum range value. 3 access points have been placed in the production hall in such a way that none of the route fragments is beyond its reach (Figure 7). The area of operation of each access point must partially overlap the area of operation of the neighboring one. AccessPoint devices are placed on the walls of the hall in places where power cables necessary for their operation can be easily connected.

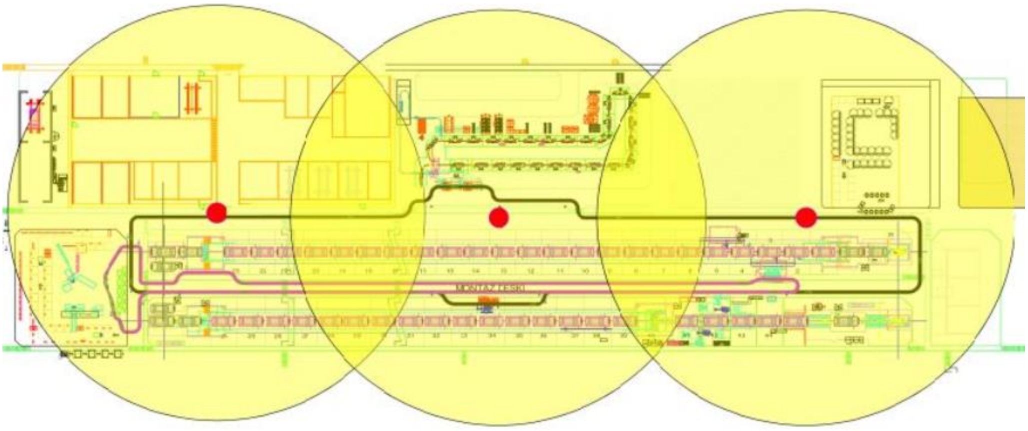

Figure 7. Location of wireless network access points within the car assembly hall.
Source: own study based on a technological audit of the FCA car assembly hall.

In order to ensure the correct operation of the entire infrastructure in which several trolleys will move, a local PLC acting as a master, i.e. a superior device, has been used. It is connected directly to one of the access points via a network cable. All AGV trucks communicate with the main controller and he manages their operation in such a way that the movement is smooth and collision-free.

3. Optimization of a collision-free route using wireless communication – controlling and previewing the route

An HMI panel has been mounted to the PLC controller, which serves as the master device, displaying an overview view of the route and information on the position of a specific trolley, battery charge status and operation signaling. In the event of any forklift failure, emergency stop or low battery level, an employee near the panel will be informed about this fact by means of a message, a light signal and a sound signal, the sound and volume of which depends on the type of notification. Extremely dangerous situations, such as emergency stop or lack of detection by the magnetic tape sensor, are signaled by a loud alarm and a flashing red indicator. Lower priority alarms are indicated in yellow and a less loud signal.

Each vehicle has a button on its housing through which the operator confirms that all the necessary elements have been loaded on the trolley and can start the transport journey. At the same time, the PLC controller mounted on the trolley sends information about the start to the master controller, hereinafter referred to as the Master. The cart reads every tag it encounters on its way and performs the information assigned to it, but also sends a data frame contained in the tag. Thanks to this information, the Master knows the position of individual trolleys and displays it on the panel. When the vehicle enters the collision zone, the master controller will receive such information. If at this moment another trolley approaches the same zone, the algorithm stored in the controller program sends information to the trolley about the need to stop. If the first vehicle leaves the collision zone, i.e. its reader registers a specific tag, only then the second vehicle will receive permission and continue driving. In this case, it is necessary to use an exit tag because the time delay may be unreliable. For example, when an obstacle in the form of another traffic participant suddenly appears on the route, the vehicle will not be able to leave the collision zone. Due to the laser sensors used, there will be no physical collision. The problem arises when both carts detect an obstacle in the form of the other cart and neither of them will be able to continue driving.

A specific process is the transport of small elements to the assembly line. On one platform there are elements for one car, but they are assembled in different zones of the line. Then the platforms must be separated and each must follow the car to which the transported components belong on the line. When the vehicle transporting small elements to the assembly line reaches its destination, the hitch connecting the trolley with trolleys will rise, unfastening the set. When the controller receives information from the sensor that the hitch has been lifted, the trolley moves to the place where it receives empty wagons that have been separated from each other. When the trolley reaches the pick-up location, it waits for information whether the empty trolleys are ready for collection. The local PLC controller managing the trolley collection mechanism verifies whether the trolleys are prepared. If the operation has been performed and the Master has sent information that the AGV trolley is waiting for them, the platforms are pushed to the trolley. The vehicle checks that the hitch is in place and then moves the hitch down. After this operation, the truck sets off on its way to the place of loading (Figure 8).

Figure 8. AGV trolley with trolleys transporting small assembly elements (technological audit). Source: own study based on a technological audit of the FCA car assembly hall.

In the case of cockpit transport, the situation is simpler because the trolley is circulating with the same set of platforms all the time. Then, each element from the trolley is assembled on the same station of the line, so there is no need for the transport platform to move together synchronously with the conveyor transporting the assembled vehicles. Only when all the boards on the platforms are taken away, the line employee confirms the possibility of its departure with a marker on the trolley.

4. Selection of elements responsible for avoiding collisions with AGVs and other road users

An AGV moving within the working area of other vehicles and people must be equipped with systems that ensure safe and predictable operation. The most important sensor responsible for safety is the laser sensor (Figure 9). The use of such solutions allows you to increase the speed of the vehicle. The vehicles are equipped with the HOKUYO UAM-05LP-30 device, in the TOF (Time-of-Flight) technology, which is based on the measurement of the time in which the light beam hits the object, is reflected and returns to the sensor. The maximum detection area is 2700. The security zones created by the scanner allow you to assign actions to a specific zone. If the obstacle is more than 2m but less than 6m, the vehicle reduces its speed by half. If the obstacle in front of the cart is between 0.5m and 2m, the speed is 30% of the maximum speed. If the sensor detects an object closer than 0.5m in front of you, it will stop the vehicle until the obstacle is removed.

Figure 9. HOKUYO UAM-05LP-301 laser sensor.
Source: https://automatykab2b.pl (access: 10.05.2023).

Figure 10. Main safety switch on the AGV (technological audit).
Source: own study based on a technological audit of the FCA car assembly hall.

Another element responsible for safety is the safety switch, which is placed in an easily accessible place, at the same time in a place that prevents its accidental pressing. The button should be used in dangerous situations, such as loss of control of the vehicle or breakdown on the production floor. The purpose of the switch is to directly, mechanically cut off the power supply to the vehicle, which causes it to stop immediately (Figure 10).

The operation of an autonomous truck should be visible to the environment. For this reason, the vehicles are equipped with light indicators showing the status of the vehicle (Figure 11). If the vehicle is in motion, it will flash amber to indicate movement. Each turning maneuver is signaled by LED lights located in the front of the stroller. Their strong orange light acts as a turn signal when the vehicle is about to make a turn. If both lights are on continuously, it is a signal that the vehicle will go straight at the intersection. Also, each emergency situation is visualized by flashing lights similar to emergency lights.

Figure 11. Traffic lights showing the status of the AGV (technological audit).
Source: own study based on a technological audit of the FCA car assembly hall.

5. Conclusions

When designing the route, the existing infrastructure of the facility should be taken into account and efforts should be made to simplify communication routes.

Selection of reliable and proven solutions available on the market facilitates the operation and servicing of the entire system.

RFID surveillance is required for junction and junction zones.

Each of the AGVs should be constantly within the range of the wireless network according to the access points of the AccessPoint type with partially overlapping areas of the adjacent zones.

Despite the development and reliability of wireless communication systems, security sensors must operate independently of network access.

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Numerical verification of transitions reducing stress concentration in the interference fit according to DIN 7190 standard

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Abstract: DIN 7190-1:2017-02 Interference fits – Part 1 can be used to verify the quality of a press fit in an axially loaded cylindrical joint or in torsional moment: Calculation and design rules for cylindrical self-locking pressfits. The standard also includes geometries for the transitions between the hub seating and the unloaded contact pressure surface. The article presents the results of a series of numerical analyses to determine the pressure distribution in the node in question depending on the variant of the geometric shape of the transition between adjacent cylindrical surfaces. A solution has been identified to minimize fretting corrosion without increasing the nominal push-in value. Determining the correct transition geometries and axial projection values is only possible through finite element method simulation.
Key words: interference fit, press fit, numerical analysis, FEM, contact pressure.

1. Introduction

In rail vehicles, the seating of the wheel on the axle is realized by a press fit. This joint, under normal operating conditions, is exposed to significant torsional and bending fatigue loads. Ensuring the required level of safety of the described connection is achieved by preventing the occurrence of slippage and plasticization while maintaining the required value of pressure in the contact pair. DIN 7190-1:2017-02 indicates the relationship of the design rules for the transition between the contact pressure area and the unloaded surface.

The purpose of this study is to determine the effect of different configurations of the transitions between the pressed part and the relieved part on the value and distribution of pressures in the extreme areas of the fit. The conclusions of these considerations may contribute to the formulation of a criterion for the acceptance of numerical exceedances in the interference area during wheel calculations in accordance with EN 13979-1:2020.

2. Transition geometries between the contact pressure area and the unloaded surface according to DIN 7190-1:2017-02

The DIN 7190-1:2017-02 standard indicates two examples of shaping the axle journal geometry at the extreme fragments of an interference fit connection, which are mainly subjected to cyclic bending. Figure 1 shows the optimization of the nature of the transition between areas of geometry with varying values of diameters. In contrast, Figure 2 illustrates the transition in the journal geometry made by undercutting, which should be used for areas with similar diameter values.

In this work, both the solution in Figure 1 and (in different variants) as well as the effect of hub axial projection – dimension a shown in Figure (2).

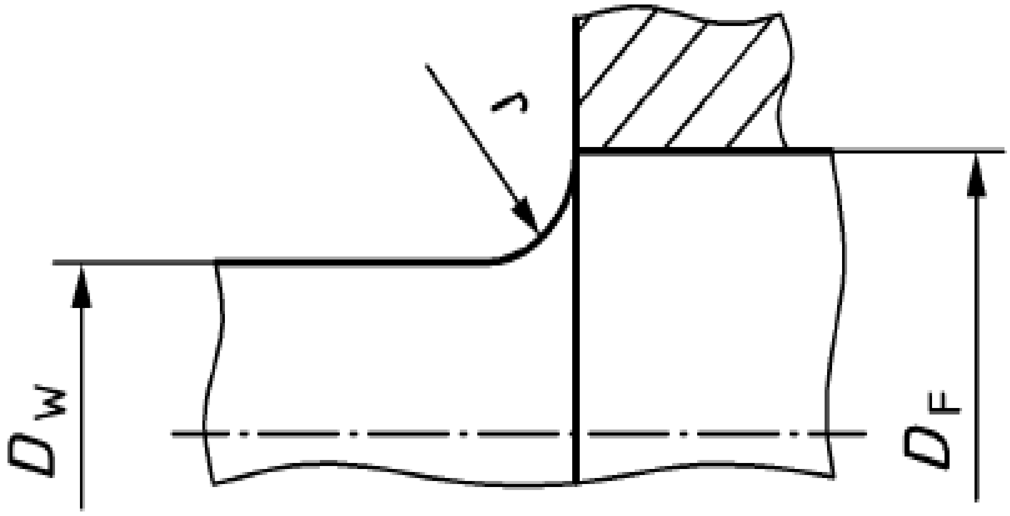

Figure 1. Optimized transition between different diameters (DIN 7190-1:2017-02).
Source: DIN 7190-1:2017-02.

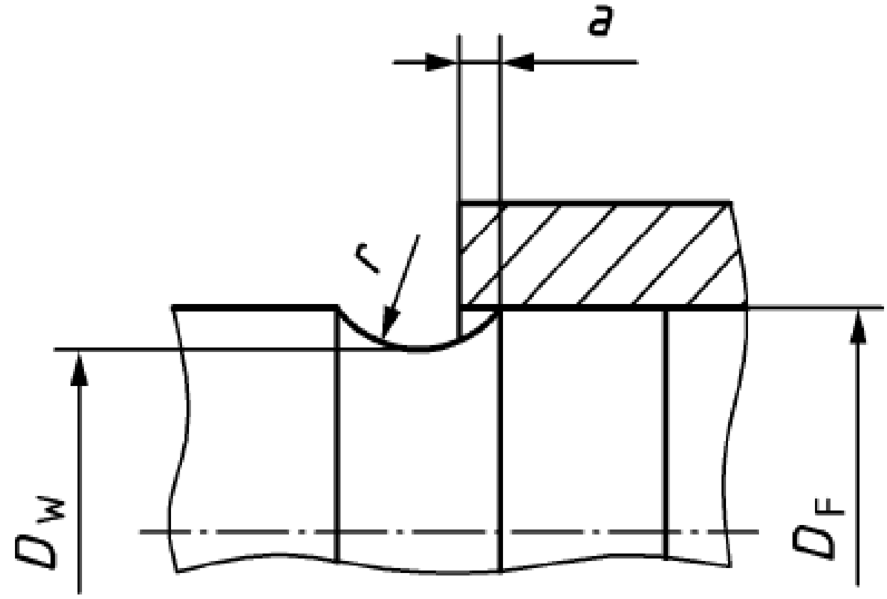

Figure 2. Example of optimizing the transition by undercutting the journal and projecting the hub (DIN 7190-1:2017-02).
Source: DIN 7190-1:2017-02

3. Selection of geometric dimensions of the connection and determination of analysis variants

In this work, numerical analyses were performed for 15 combinations of variants of the transition between the deposition and the unloaded surface of the joint in question, collected in 4 main groups details the geometric dimensions adopted.

Figure 3 shows the area subject to further consideration by detail A. Figures 4-7 show variants of the analyzed area, divided into groups for which calculations were carried out using the Finite Element Method.

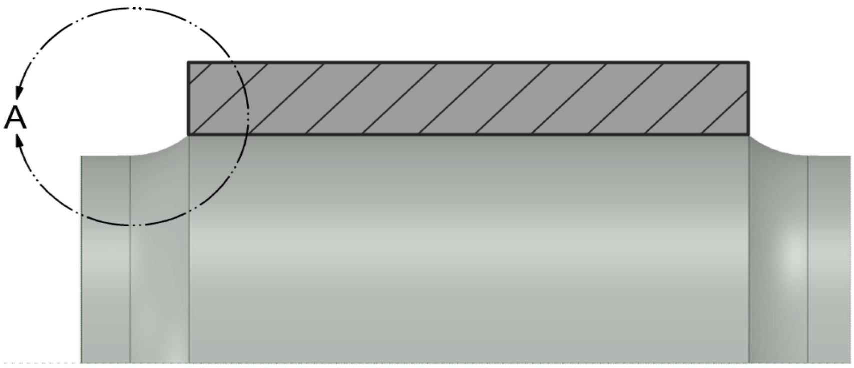

Figure 3. Cross section of the analyzed interference fit.
Source: own elaboration.

Table 1
Summary of the analyzed variants of the transition between the interference-fit connection and the unloaded surface

Group	**Variant**	**D_F/D_W [-]**	**$r/(D_F-D_W)$ [-]**	**D_W [mm]**	**r [mm]**	**a [mm]**
0	**W00**	1.1	2	174.5	35	0
	W01	1.1	-	174.5	-	0
	W02	1	-	192	-	0
1	**W1**	1.025	2	187.3	9.4	0
	W2	1.05	2	182.9	18.2	0
	W3	1.15	2	167	50	0
	W4	1.2	2	160	64	0
2	**W5**	1.1	0.5	174.5	8.8	0
	W6	1.1	1.25	174.5	21.9	0
	W7	1.1	2.75	174.5	48.1	0
	W8	1.1	3.5	174.5	61.3	0
3	**W9**	1.1	2	174.5	35	-8
	W10	1.1	2	174.5	35	-4
	W11	1.1	2	174.5	35	4
	W12	1.1	2	174.5	35	8

Source: own elaboration.

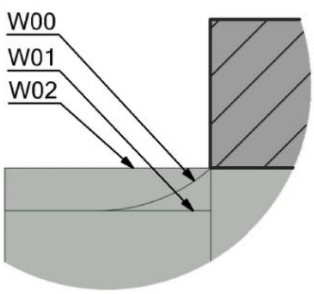

Figure 4. Graphic representation of the variants in group 0.
Source: own elaboration.

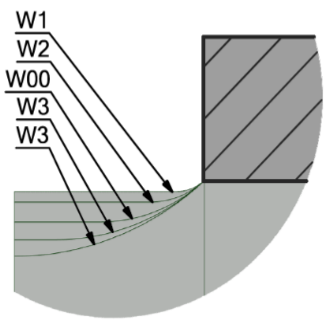

Figure 5. Graphic representation of the variants in group 1.
Source: own elaboration.

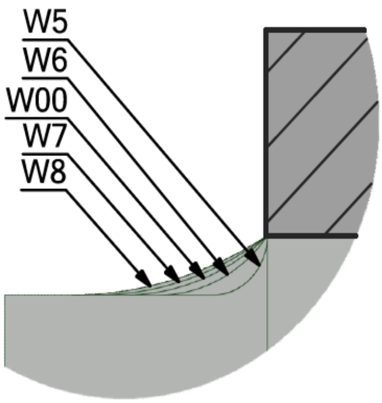

Figure 6. Graphic representation of the variants in group 2.
Source: own elaboration.

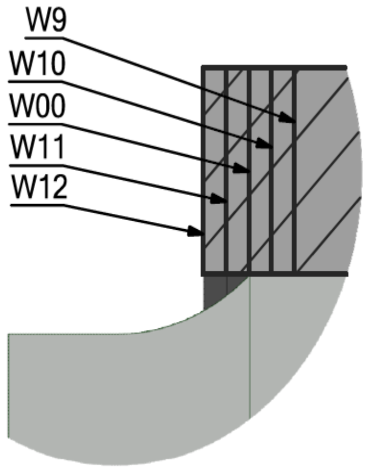

Figure 7. Graphic representation of the variants in group 3.
Source: own elaboration.

According to the EN 13260:2020 standard, the interference value for the assumed nominal connection diameter of 192 mm should be in the range of 0.192 mm to 0.288 mm. For the purposes of the work, a constant value of the insertion of 0.2 mm was adopted.

DIN 7190-1:2017-02 recommends fulfilling the following relationships between transition diameters and the radius for leveling the notch effect.

$$\frac{D_F}{D_w} \approx 1.1 \quad \frac{r}{(D_F - D_W)} \approx 2$$

The W00 variant is an example that meets the above assumptions, which is why it was adopted as a reference for the remaining combinations of dimensions that were analyzed in the work in question.

4. Verification of pressure distribution in the longitudinal section of an interference fit connection

Based on the analyses carried out, the effect of the shape of the geometry of the transition between diameters on the pressure value in the interference fit connection at the outer areas of the contact pair was observed. In selected combinations of shaping the transition geometry, it is possible to exceed the yield strength of the material of the associated objects. Table 2 contains a summary of the results for the considered cases, including the maximum value of pressure in the contact pair along with the percentage difference compared to the reference variant – W00. The highest pressure values were observed at the edge of the contact.

Table 2
Summary of maximum contact pressures with percentage difference from the reference variant

Group	Variant	p_{MAX} [MPa]	Difference [%]
0	**W00**	76.92	0.00%
	W01	47.07	-38.80%
	W02	76.01	-1.18%
1	**W1**	77.09	0.22%
	W2	76.82	-0.12%
	W3	76.91	-0.01%
	W4	76.90	-0.03%
2	**W5**	58.45	-24.01%
	W6	75.27	-2.14%
	W7	77.58	0.86%
	W8	77.20	0.37%
3	**W9**	76.06	-1.12%
	W10	76.64	-0.36%
	W11	228.33	196.86%
	W12	313.20	307.20%

Source: own elaboration.

A graphical representation of the maximum pressures is provided in Figure 8 highlighting in green the values determined for the reference case. Note the significant pressure increase at the contact edge for cases W11 and W12, where the value of the axial projection was positive.

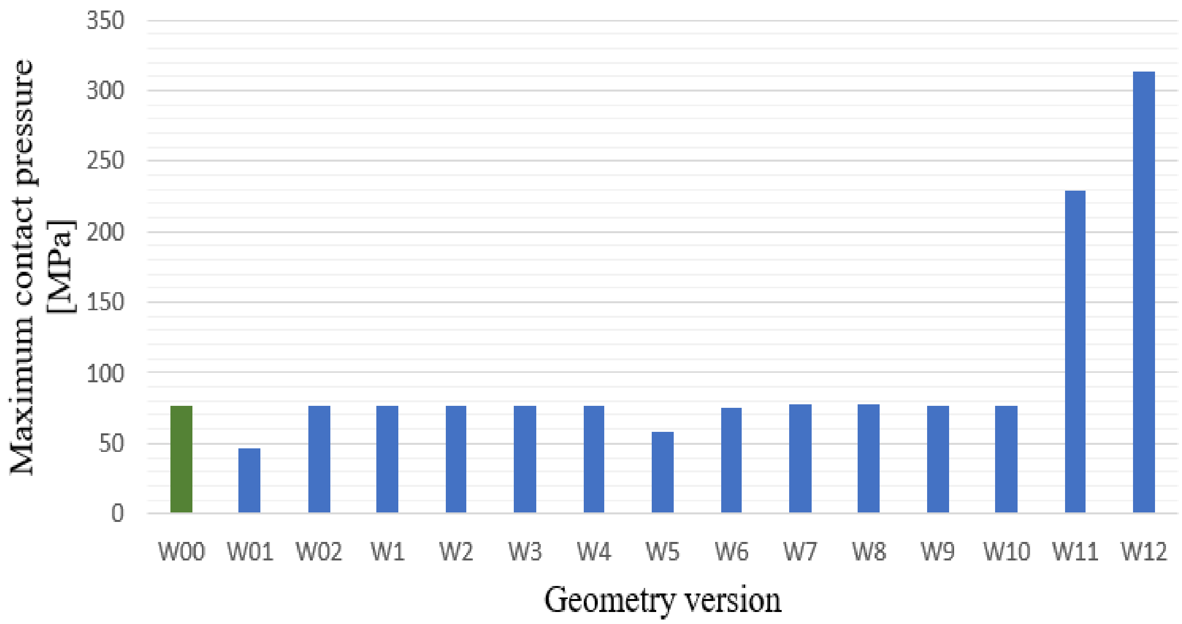

Figure 8. Maximum contact pressure for all variants.
Source: own elaboration.

Figure 9 and Figure 10 show the characteristic pressure distributions among all the examples analyzed. Due to the symmetrical nature of the graph, the results are presented only for half the length of the interference fit connection.

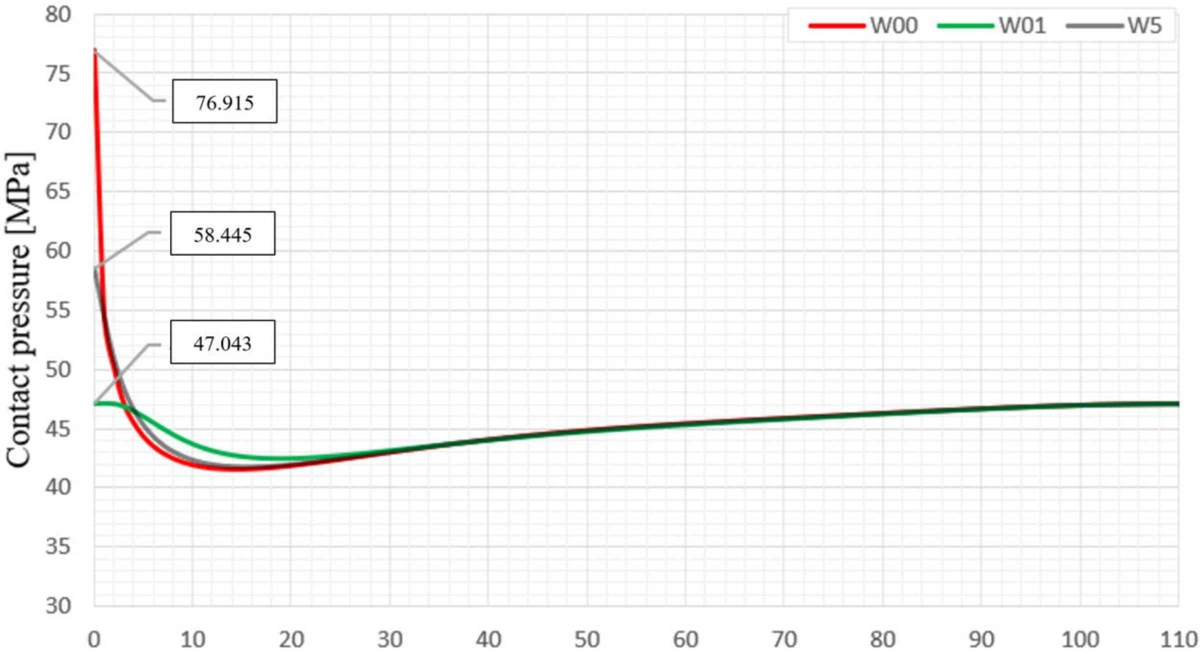

Figure 9. Distribution of contact pressure along an interference fit connection. Variants W00, W01, W5.
Source: own elaboration.

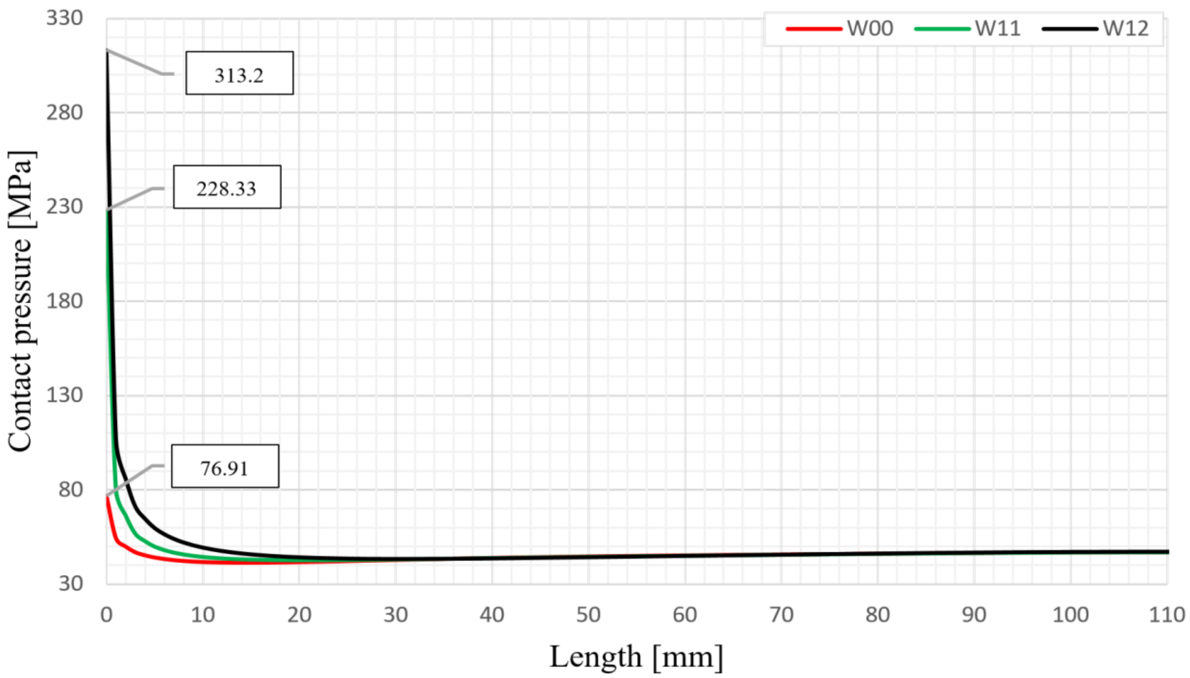

Figure 10. Distribution of contact pressure along an interference fit connection. Variants W00, W11, W12.
Source: own elaboration.

The axial projection a, shown in Figure 2 and Figure 7 with a positive value, causes an increase in the stiffness of the hub, resulting in higher surface pressure at the joint in the hub edge area (Romanowicz, Sanecki, 2014; Nwe, Pimsarn, 2021). This is an effective method of preventing fretting corrosion without the need to increase the interference value (Kowalski, 2021; Michnej, Guzowski, 2019). If the hub is projected, this method can be used for both the diameter change in the transition (Figure 1) and the relief groove (Figure 2). In both cases, the following rule applies: $a \geq 0$ (according to the provisions of DIN 7190-1:2017-02).

The map of the distribution of reduced stresses in the longitudinal section of the interference fit connection is shown in Figure 11, while the distribution of radial displacements is shown in Figure 12.

Figure 11. Stress distribution in the longitudinal section of an interference fit connection variant W00. Source: own elaboration.

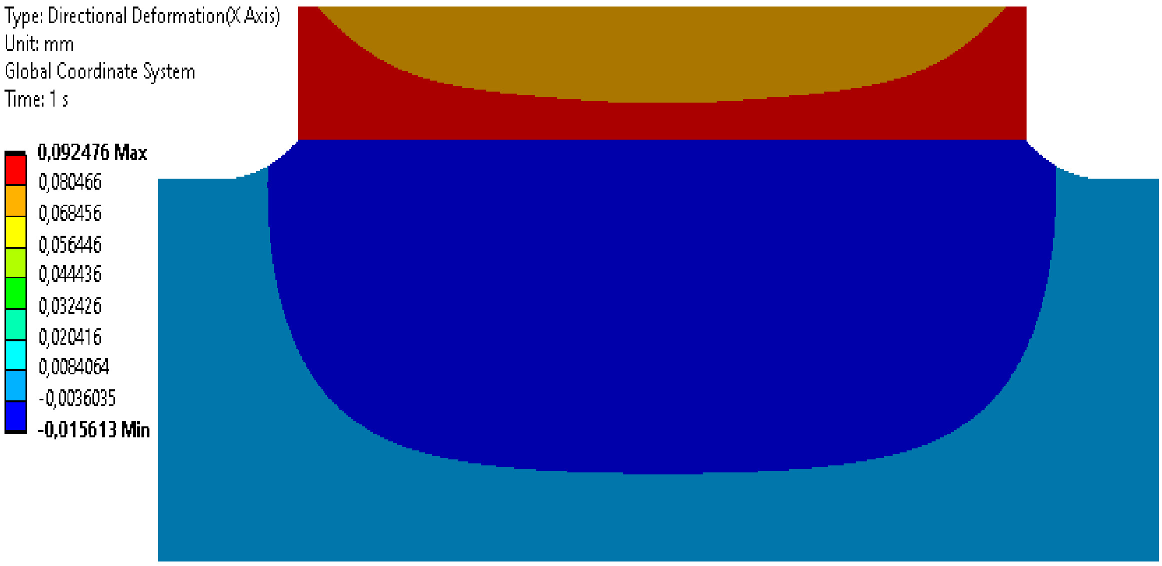

Figure 12. Stress distribution in the longitudinal section of an interference fit connection variant W00. Source: own elaboration.

5. Conclusions

When designing the geometry for seating a wheel on the axle of a wheelset, use transitions that level the notch effect on the journal surface. It is also necessary to ensure the required value of pressure in the area of the contact edges of the associated objects in the interference fit. In the case of complex transitions, it is recommended to perform an FEM analysis is recommended for detailed verification of the stress and pressure distribution across the joint area.

A trade-off between reducing interference in the entire joint and ensuring a sufficiently high contact pressure to prevent fretting corrosion can be found by finite element method calculation.

Further research is required in the subject area to create complete acceptance criteria for areas containing numerical stress concentrations in the zone of compressive action during wheel calculations in accordance with EN 13979-1:2020.

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Methods for evaluating the effectiveness of investments related to the purchase of public transport rolling stock

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Abstract: The activity of the municipal transport company is related to the allocation of financial resources for the implementation of investment projects related to the purchase of means of transport and their operation. Making investment decisions requires an assessment of their effectiveness, which allows for the choice of the most favourable solution among the few assessed. In the work, based on the analysis of the investment assessment methods used in practice, i.e. the cost-benefit analysis (CBA analysis), the analysis of the life cycle cost (LCC analysis), selected indicators with high usefulness in the decision-making process of purchasing means of transport were characterized. The CBA analysis, which presents an economic approach to assessing efficiency, does not fully take into account one of the most important features of public transport rolling stock, which is reliability. The LCC analysis can eliminate the above limitations. In the analysis of the efficiency of projects related to the purchase of public transport rolling stock, it is insufficient to evaluate the acquisition cost, but an LCC-oriented approach is necessary, including maintenance and operating costs, which constitute a major part of total costs.
Key words: LCC analysis, effectiveness, public transport rolling stock.

1. Introduction

The main objective of operating a public transportation company in a competitive environment is to receive benefits for providing transportation service to the city under the terms and conditions found in contracts defining the tasks of the carrier and the standard of services offered. The requirements determine the parameters of the vehicles, such as the requirement for a low floor, passenger information solutions, or the ticketing system. In order to carry out transportation activities, it is necessary to undertake investments related to the purchase of rolling stock and the provision of adequate technical facilities to maintain and operate vehicles. Continuous development is also conditioned by the tasks set for modern enterprises by the country's legal authorities and the European Union. The provisions of the Public Procurement Law bind investments carried out by municipal transportation companies. It defines the priority directions for procurers, particularly the purchase of innovative or sustainable services, and indicates the use of the product life cycle cost calculation.

2. Rolling stock investments in public transport

The definition of the concept of investment in the PWN Lexicon speaks of economic outlays aimed at introducing new or enlarging existing fixed assets (Kaczorowski, 2004). Investing involves making expenditures in anticipation of obtaining the desired results, which always involves risk. From the point of view of the impact of investment projects on the transport potential of a public transportation company, new, replacement, modernization and development investments can be distinguished. Due to the time of preparation, implementation, and use, all rolling stock investments of the municipal transport company can be classified as long-term investments, characterized by high capital intensity, with a significant impact on the external environment. This results in the:

- the length of the calculation period (covering the entire economic life cycle of the investment);
- estimating financial flows over a 15 ÷ 35-year horizon (for rolling stock in general);
- taking into account changes in the value of money;
- accounting for forecast uncertainty.

3. Criteria for evaluating the effectiveness of investments

When selecting the most advantageous investment option, there is a problem of decision-making, which is a complex task or issue that needs to be addressed or resolved. It arises when the decision-maker (i.e., the entity making the decision) seeks the most desirable action (decision, option) from among the many actions (decisions, options) that are permissible. Solving (tasks or problems) is a search process leading to finding the right and accurate solution (Zak, 2005). The assessment of the effectiveness of investments in the rolling stock of public transport is based on the analysis of sets characterized by high complexity. Tailored analytical methods, which require appropriate preparation and development of relevant assessment criteria, are tools to assist in solving decision-making problems.

The assessment of the effectiveness of investments related to the collective transport rolling stock is a calculation carried out for a municipal enterprise, which selects the most advantageous solution from the evaluated ones. It involves performing an efficiency analysis for each case and, based on the criterion adopted, making a choice in terms of cost-effectiveness. It is essential to limit the analysis only to aspects that are reflected in a given activity. Based on the conducted research (Szkoda, 2017), the following methods may be used to assess the effectiveness of investments related to the purchase of public transport rolling stock:

- Cost-Benefit Analysis;
- Life Cycle Cost Analysis.

The above methods are complementary, the LCC cost analysis allows for finding the optimal relationship between the costs of acquiring and operating a rail vehicle, while the benefit-cost analysis provides the opportunity to determine the limit expenditures and safety margins for a given acquisition option.

4. Cost-Benefit Analysis

The cost-benefit analysis reflects the economic side of performance evaluation. Many scientific papers are devoted to this topic. The essence of this method is to perform all calculations using mathematical algorithms, reflecting the financial benefits of given projects in relation to the required expenditures and future costs.

In the context of a carrier, several variants corresponding to technical requirements are compared in terms of decision indicators which are:

- Payback Period (PP), or the time after which the benefits of implementation will offset the outlay, in simple terms:

$$NI = \sum_{t=1}^{n} ND_t \quad (1)$$

where:

NI – the value of investment expenditures incurred
ND – the value of annual financial surpluses from the implementation of the project
$t = 0,1,2, \dots, n$ – the consecutive year of the calculation period (Sierpińska, Jachna, 1994).

- net present value (NPV), i.e. the discount method corresponding to the sum of differences between benefits and expenditures for each year of the calculation period, discounted at the time of commencement of the investment. For a situation where the entire expenditure is incurred in the first year of the investment, the indicator is calculated according to:

$$NPV = \sum_{t=0}^{n} (B_t - C_t) \cdot CO_t - N \quad (2)$$

where:

B_t – the total value of benefits in year t
C_t – the total value of expenditures in year t
N – investment expenditures
CO_t – discount factor for subsequent years of the calculation period (appropriate for the adopted interest rate level)
$t = 0,1,2, \dots, n$ – the consecutive year of the calculation period (Sierpińska, Jachna, 1994).

- Internal Rate of Return (IRR), which is the discount rate at which the net present value is zero:

$$\sum_{t=0}^{n} \frac{CFO_t}{(1+IRR)^t} = \sum_{t=0}^{n} \frac{CFI_t}{(1+IRR)^t} \quad (3)$$

where:

CFO_t – total expenditure of year t
CFI_t – cash inflows in year t (Dyr, Kozubek, 2013).

- Benefit-Cost Ratio (B/C Ratio), i.e. the profitability ratio, which is the quotient of the discounted benefits from the adopted calculation period and the discounted values of the total costs of a given project. It is calculated according to the formula:

$$PI = \frac{\sum_{t=0}^{n} \frac{CFI_t}{(1+r)^t}}{\sum_{t=0}^{n} \frac{CFO_t}{(1+r)^t}} \quad (4)$$

where:

CFO_t – total expenditure of year t

CFI_t – cash inflows in year t

r – discount rate (Dyr, Kozubek, 2013).

Based on the analysis of the calculated indicator values, we receive information on the investment's profitability, neutrality or unprofitability. The cost-benefit analysis, which presents an economic approach to assessing the effectiveness of projects related to shaping the transport capacity potential, has significant limitations:

- it requires a comprehensive database of financial inputs necessary in forecasting elements of the profitability calculation, such as sources of financing, working capital requirements, depreciation costs, capital expenditures necessary to create a given investment, costs of its operation, and benefits associated with a given project, which must be expressed in monetary units over the years of the investment,
- in view of widely accepted standard methods for forecasting the cost of operating public transportation assets over a relatively long existence cycle, heuristic methods are used in cost-benefit analysis. Their basis is a qualitative evaluation of facts, intuition, and the experts' individual association scheme being a kind of cognition and prediction algorithm,
- in these methods, the prediction of the future is not an extrapolation of the regularities detected in the past, but the forecasting of possible variants of the development of phenomena and presentation of the most realistic variants, which affects the time-consuming estimation of input data,
- according to the recommendations of the World Bank and the United Nations Industrial Development Organization (UNIDO), the estimation of performance indicators at the stage of the feasibility study should be made with an accuracy of ±30%, in the pre-feasibility study this tolerance is ±20%, and in the evaluation of the final version of the project it should be reduced to ±10%. In the case of rolling stock projects characterized by very high capital expenditures, this is too large a margin of error, unacceptable to transport companies.

The cost-benefit analysis also has limitations due to its inability to fully take into account one of the most important characteristics of transportation assets, which is reliability as characterized by RAMS (Reliability, Availability, Maintainability, Safety) characteristics. In order to take this aspect into account, life cycle cost (LCC) analysis can be used, which reflects the engineering approach to assessing the effectiveness of investments.

5. Life cycle cost analysis

In the analysis of the effectiveness of undertakings related to the purchase or modernization of means of public transport, it is not sufficient to assess the acquisition costs, but an LCC-oriented approach is necessary, including operating costs (maintenance and use). The work carried out showed that the share of operating costs exceeds 65% of total costs, constituting an essential part of LCC. The research work performed also indicates the need to include energy consumption costs in the LCC model of public transportation modes, and in the case of conventionally powered buses, fuel costs and environmental impact costs. The in-service fuel consumption is a baseline figure for determining the energy consumption of a vehicle powered by an internal combustion engine, and in some cases, it can be used to determine the cost of CO2 emissions and the cost of pollutant emissions over the life of the vehicle. Figure 1 shows the share of energy costs in the LCC of a tram over a 30-year period of operation. The price of electricity was adopted in accordance with the provisions of the Act on Freezing Electricity Prices, according to which the maximum price of electricity in 2023 for local governments, utility customers and companies is 0.785 [PLN/kWh]. The graph shows that the share of energy costs is approximately 23.5% of the total costs.

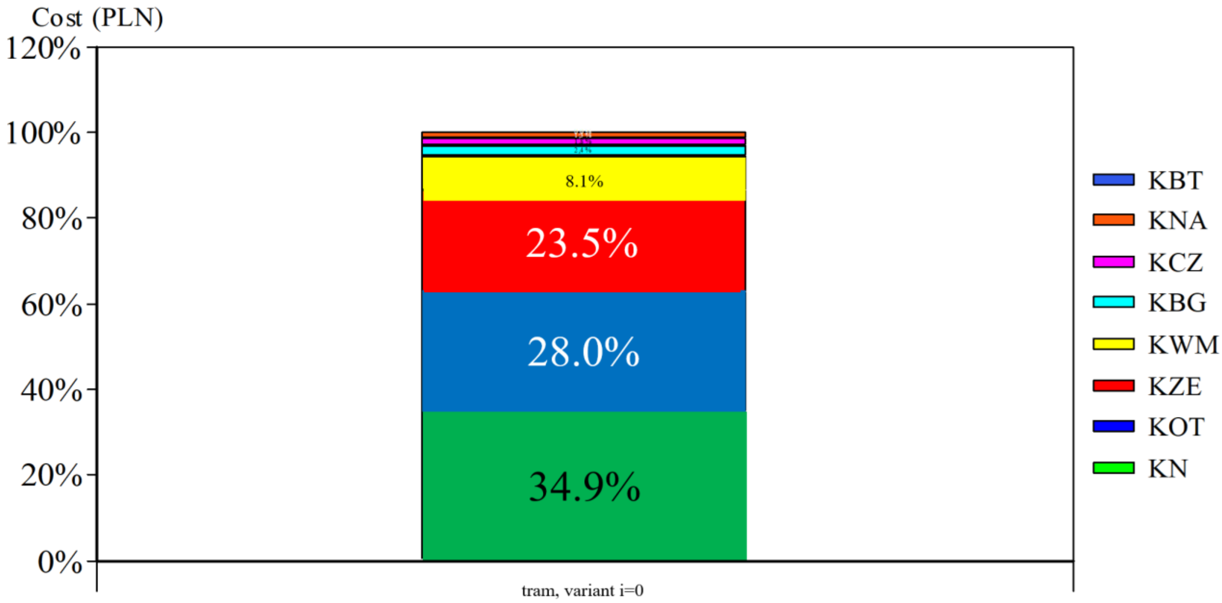

Figure 1. LCC structure of a tram in 30 years of operation.
Symbols: KN – acquisition costs, KOT – m aintenance costs, KE - electricity consumption costs, KWM – motormen's wages, KCZ – vehicle cleaning costs, KBG – lack-of-readiness costs, KNA – emergency repair costs, KBT – technical testing costs.
Source: own elaboration.

Figure 1, based on the requirements of the PN-EN 60300-3-3:2017-07 standard, presents the procedure for assessing the efficiency of public transport rolling stock using LCC. For a detailed description of the various stages, see Szkoda (2017). In the first stage, assumptions and input data are developed that relate to the design features of the vehicle, operating conditions and maintenance requirements. This stage also identifies the analysis objectives regarding evaluating the costs of the vehicle's operating phase, identifying dominant costs, or determining costs that affect LCC the most. The next step is to perform the RAMS reliability analysis. The indicators taken into account depending on the degree of detail adopted include, among others: technical readiness A, expected mean time to failure MTTF, and expected mean time between failures MTBF as above.

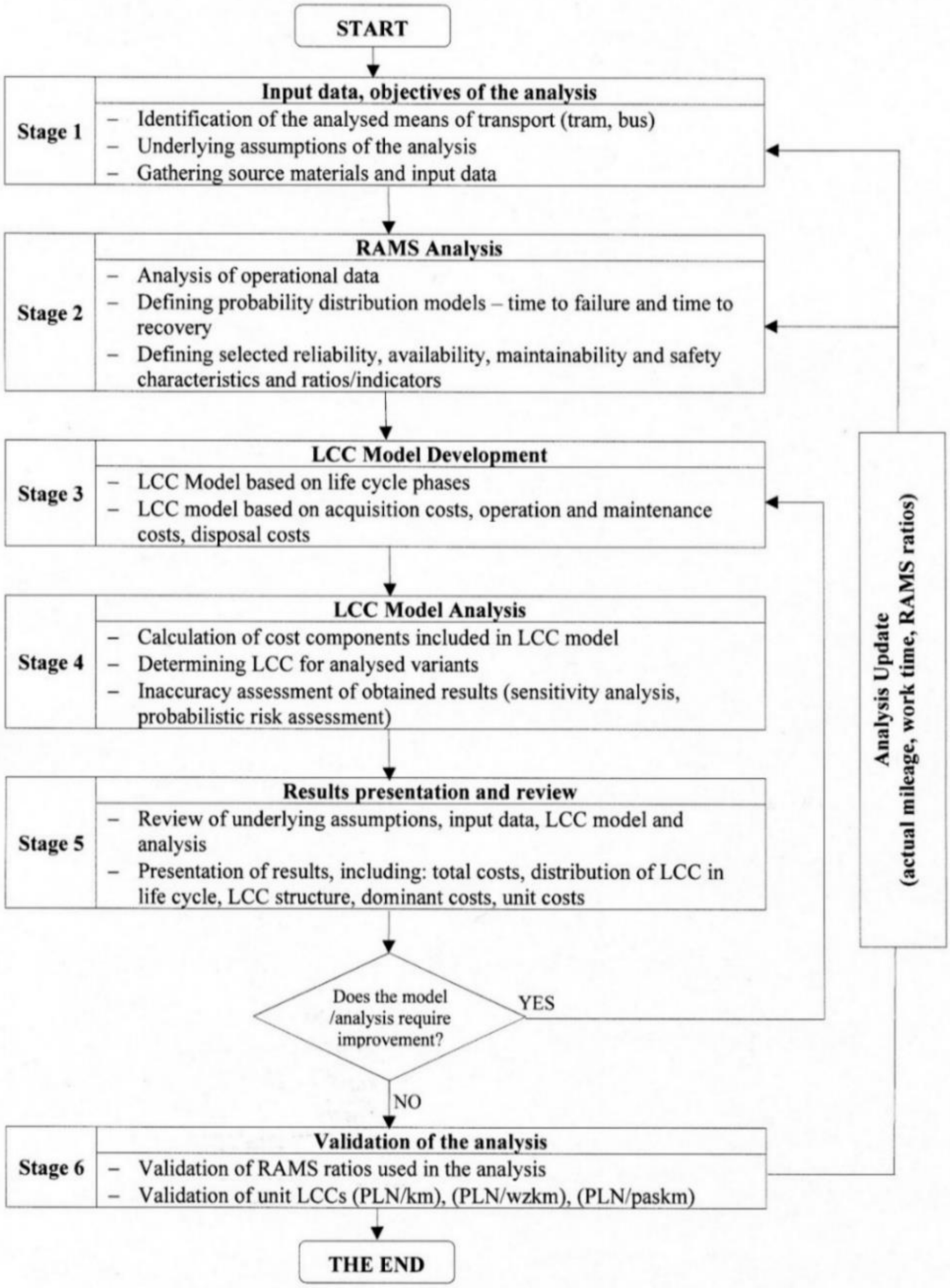

Figure 2. LCC calculation procedure for collective transport rolling stock.
Source: own study based on *Kształtowanie potencjału przewozowego przedsiębiorstw transportu kolejowego*, M. Szkoda, 2017, Kraków: Publishing House of the Cracow University of Technology.

Features characterizing vehicle reliability are essential for building a cost model and impact vehicle operating costs the most. The ability to identify the cost of unserviceability of a public transportation fleet vehicle is one of the advantages of LCC analysis, as it allows for capturing the relationship between losses and the unreliability of the facility. The third stage involves a simplified representation of reality, i.e. converting the assumed characteristics into numbers representing costs.

Assumptions from previous stages and various usage and maintenance scenarios are taken into account here to guarantee the created model's realistic nature. It is necessary to ensure the model's simplicity, which will allow it to be easily understood and used. During the development of the model, cost-sharing structures, vehicle allocation and estimation of cost elements and parameters are used. The first structure consists of acquisition, ownership and liquidation costs, which are divided until a form of value that cannot be expressed as a sum of costs is obtained. It is defined using mathematical formulas that include parameters of labour intensity or values of man-hour costs of repairs. A vehicle breakdown structure is one that allows the durability of a structure's life cycle to be reflected in the costs and phases. This approach guarantees that all elements that have a significant impact on the model are included in the model.

This approach is outlined in the US Ministry's program (1986) and in the EN 60300-3-3:2017-07 standard. In the next stage of the analysis, all the included cost elements are calculated and dominants are identified. It is also recommended to perform a sensitivity analysis of the impact of dominant costs and reliability parameters on LCC. The fifth stage includes the analysis of the results by verifying the fulfillment of the purpose and scope of the analysis, as well as checking the assumptions and matching the model to the purpose of the analysis. Corrections should be made if any inaccuracies are found. The final stage consists in verifying the model using data from actual operation and performing the appropriate analysis. Using in-service data, an assessment is made of the correctness and accuracy of the model's calculations, which can provide a basis for verifying the veracity of the vehicle manufacturer's assumptions.

6. Conclusions

The presented concept of using indicators in the framework of analyzing the effectiveness of rolling stock investments in public transport is described in general terms, as it is more complex in practice. The method of calculating the basic elements of the efficiency account requires accuracy in identifying costs and effects for each of the analyzed options. Correctly conducting the analysis guarantees a helpful tool in the context of evaluating the effectiveness of purchasing investments in public transport rolling stock. Furthermore, it allows decision-making for facilities characterized by a high complexity of variables affecting the operation of a municipal enterprise.

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Healthcare logistics during the epidemic crisis

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Abstract: Health security requires persistent supply of hospital services. It may also require hospitals to branch out. During the epidemic crisis, the efficiency of logistics management influences directly health security of patients and medical staff.
Key words: healthcare, COVID-19, logistics of crisis situations, supply chain.

1. Introduction

First reports about COVID-19 cases were taken public at the end of 2019. While virus was spreading all over the world, people and global organizations were becoming increasingly concerned about the health security. The escalation of a problem made COVID-19 one of the most serious global health challenges. COVID-19 was declared pandemic (Cetinkale, Aydin, 2023). It was qualify as one of the biggest global health dangers. The impact of living in constant threat on the society and individuals is shown in Maslow's Hierarchy of Needs. His hierarchy of needs indicates that safety needs should be satisfied right after physiological needs and before love and belonging needs. Epidemiological risk is a crisis. It causes lots of restrictions in daily living. The sense of safety is shaken by labour market destabilization, limited access to resources and anxiety over the health. During the crisis people are worried about their and their family's future. No one knows how the new threat works. Everybody is afraid of the consequences of the problem escalation (Ryan, Coppola, Canyon, Brickhouse, Swienton, 2020). Medical facilities and emergency services play a key role in ensuring health security. Special emphasis should be placed on the proper cooperation of hospitals and emergency medical services.

2. Hospital logistics in crisis

A crisis situation is defined as a state of real medical hazard and risk of property damage. It interferes the value hierarchy and interests of society. The feature of the crisis is the initial loss of control. If actions are not taken, the problem escalates (Zdrodowski, 2014). It is required to implement additional logistics activities to counteract the crisis. It is not possible to define what actions should be taken in each crisis. They are specific and adjusted to the type of the threat. Logistics activities in a crisis should embrace supply, transport and different types of services, including medical services. Regardless of the type of threat, the main objective of crisis logistics is to protect victim's life and health and meet their basic needs (Mroczko, 2016).

Hospitals play a crucial role in supply of medical services. They participate in removing health effects of the crisis. Hospitals are also kind of the logistics centres. They hold lots of logistics activities, such as material and people transportation, storage, supplying or supply of services (Kautsch, Cięciak, 2018). Hospitals operate in the following areas (Dembińska-Cyran, 2005):

- inventory management – ordering, taking deliveries, control over stock levels, choosing the inventory methods;
- transport management – patients transport, management of the flow of people in hospital, management of the products transport at the facility;
- management of the products distribution at the facility, choosing the distribution strategy;
- locating patients on the wards;
- management of other processes, such as sterilization of materials, laundering, food management etc.

The occurrence of a crisis forces medical facilities down to execute all this processes in particular conditions. It is also often required to extend the range of activity.

3. Logistics activities of the X Hospital in crisis

The COVID-19 pandemic posed many challenges to the logistics organization of the X hospital. In new, uncertain reality, it was necessary to get to grips with unknown disease. Every day there was more and more patients who required the treatment. Simultaneously there was less of medical staff, for instance because of quarantine. Some changes in the hospital activities arose not only from executive cadre decisions, but also from the imposed guidelines.

The aim of the article is to show some of logistics activities that were done in the beginning of the COVID-19 pandemic. Authors put special emphasis on transport, supply and distribution.

4. Works and external transport

To precisely characterize changes that were done during the epidemiological risk, authors divided transport into two areas – works and external. External transport involves transporting patient to the hospital. Works transport includes management of the flow of people at the facility.

The main challenge of external transport was to split patients up into two groups. First group could be transported straight into the Emergency Department. The second group consisted of patients with suspicion or recognition of COVID-19. It was crucial to shut COVID-19 patients off from the other patients. Areas of the highest risk of virus transfer were designated. They were emergency department waiting room and ambulance ramp. To minimize the risk, the route of ambulances was changed. COVID-19 patient was transported straight into a padded room. Then the ambulance was parked up in the named parking lot and sterilized. Hospital also took care of the ambulance team safety. There was designated the place for disinfection and exchange a work suit for “clean”. The place was divided into three zones. First “contaminated” zone was intended to take contaminated work suit off. Second “sanitary” zone was equipped in a shower and a toilet. The last “clean” zone was dedicated to put on new clothes. Figure 1 shows the layout of the zones in the disinfection area.

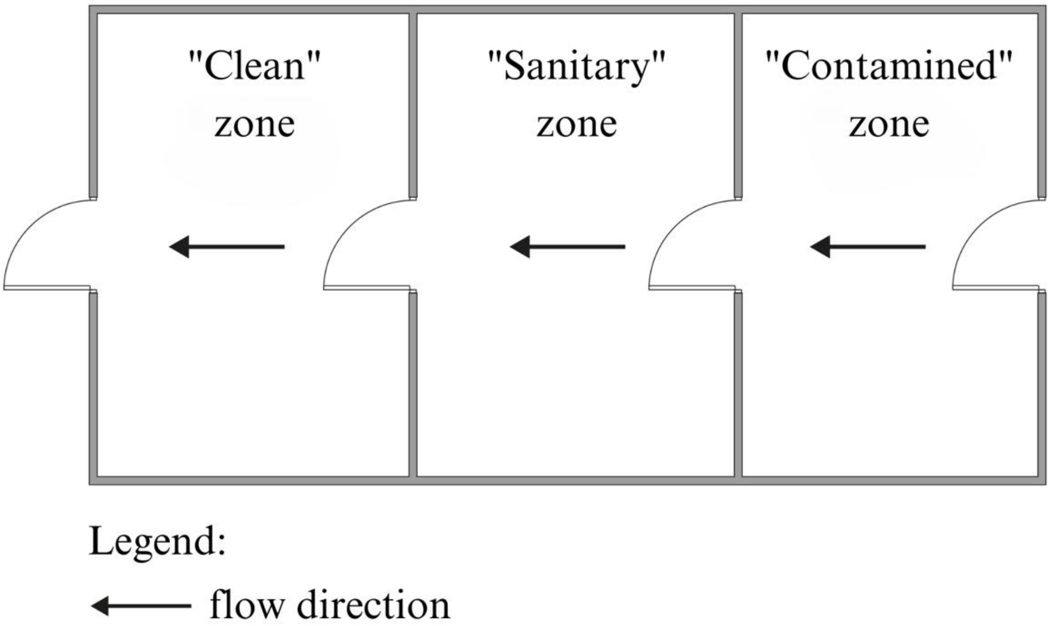

Figure 1. The layout of the zones in the disinfection area.
Source: own elaboration.

Regulating the flow of people in hospital was very important issue in the context of ensuring the safety of patients and medical staff. Restrictions included both the change of haul roads and the number of people, who were in each area at the same time. Main activities involved (https://www.szpitallimanowa.pl/, access: 01.04.2023):

- designation separate external entrances for patients with suspicion or recognition of COVID-19;
- limitation of the uncontrolled access to the hospital by closing non-controlled side entrances;
- putting contactless temperature measurement gate and hand disinfection stations at entrance doors;
- mounting combination locks and entry phones on interior doors on the hospital premises;
- demarking zones in the casualty department according to top-down guidelines – red for patients with suspicion of COVID-19 with symptoms, yellow for patients with suspicion of COVID-19 without symptoms and green for other patients. For ease of orientation in zones, coloristic floor markings were made.

5. Supply and distribution

The aim of the medicines flow management in the hospital is to provide the patient availability of appropriate medicines in the shortest possible time. Medicines supply and distribution management starts at the time of ordering products from the supplier. It also includes delivery to the hospital pharmacy, storage and the distribution in the facility to wards. The process ends when the patient gets the drug (Rosiek, 2008).

In the context of pandemic as a crisis situation, the main challenge for the hospital was to provide the continuity of supply, despite the limited availability of products. Generating high stock levels was not possible, because of the short expiration date of most drugs. In the beginning purchasing strategies were often changing. It was not possible to choose one sure strategy, because of the fluid situation on the supply market. It was essential to control the availability of products on the market every step of the way. Medicines had to be ordered suitably early before the end of stock and it was necessary to register and analyze drug consumption. It supported drug supply planning and changing the way of the management.

A pull distribution strategy was adopted. The delivery medicines from the pharmacy to award was initiated when the ward made the order electronically. In that, it was possible to maintain possibly minimal stock levels. That way, it was also easier to monitor the demand and to forecast drugs consumption. Because of the short expiration date of most medicines, First In First Out strategy was applied.

6. Conclusions

The main goal of the hospital activity during the pandemic was to save lives and satisfy basic needs of the society. It was possible only with an uninterrupted work of medical facilities. Logistics activities were focused primarily on guaranteeing availability of medicines, necessary products and the continuity of services. It was constricted because of multiple restrictions and variability of epidemic situation. Only capable organization of all processes allowed the realization of medical procedures. As always in medical sector, the high quality of services had to remain.

It is not possible to compare activities that are taken during the crisis with the decisions made during the normal state. Dynamic changes during the crisis involve making rapid decisions. Wrong decisions can lead to the escalation of the problem. During the crisis actions should be rated only in the context of situation. In most cases the success means here, that the problem did not escalate and the negative effects are minimal or did not occur.

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Analysis of operating costs of modernized diesel locomotives based on the system NAVI-CAR LOCO vehicle monitoring

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Abstract: The article presents data on fuel consumption of diesel locomotives during operation in normal vehicle shunting conditions on the example of ORION Kolej diesel locomotives. The fuel consumption of the SM 42 locomotive modernized to the 6Dm type was compared to the SM 42 locomotive without modernization. The results were developed using data from the system for monitoring the operating parameters of the internal combustion engine NAVI-CAR developed for ORION Kolej specifically for rail vehicles.
Key words: diesel locomotives, parameters monitoring, fuel consumption, modernization.

1. Introduction

Satellite navigation is widely and successfully used in various areas of life. Vehicles navigated on electronic on-board maps, controlled precisely from the place of loading to the place of delivery, portable computers equipped with telephone directories with notebooks of people's location save a lot of time and energy (Cousins, 2008).

With the development of communication, information technology and satellite navigation, it is now possible to use integrated services that allow continuous location vehicles, checking the condition of loads and their automatic monitoring. Insurance companies even require carriers to adapt their means of transport to ensure the safety of valuable goods and drivers. Mobile (radio) communication for monitoring is an important component of a successful fleet management system. Positioning systems (navigation) enable the observation and tracking of vehicle routes in real time and, if necessary, changes in strategy and vehicle routes. Continuous monitoring provides valuable information in the event of robberies, thefts, changes in logistics decisions and unforeseen traffic disruptions. The main user of positioning services is the transport industry, including rail transport, where such information brings measurable benefits to the company's financial result.

An additional advantage in equipping vehicles with a navigation system, more often called the vehicle operating parameters monitoring system is:

- full control of the operation of vehicles in real time, settlement of the actual working time of train drivers, settlement of traction teams from the tasks performed, capture of employees' abuse in the field of improper operation, recording of employees' working time;
- fuel control, reports the actual fuel consumption to the specified standard (created based on operating parameters) – monitoring of places where work was carried out – map of vehicle travel;
- visualizations of the work done on a detailed digital map of the area,

The purpose of the implementation of the vehicle monitoring system is broadly understood control of the functioning of the park vehicles and employees. Control of operating parameters allows you to influence and eliminate improper engine maintenance, for example, during the period covered by the warranty after repair.

2. Description of the NAVI-CAR LOKO vehicle monitoring system.

The locomotive operating parameters monitoring system was developed based on the guidelines and requirements of the railway carrier, F.H.U. ORION Railway. It is based on the NaviCar Lys GPS fleet management system offered by the Polish company Navi-Soft. 1). The heart of the system is the NV-GPS2-LOCO recorder. The device was expanded several times and today there are over a hundred such recorders in the final version. The whole is based on a standard GPS recorder by Navi-Soft, in the NV-GPS2-Voice and NV3 versions, it has an extensive measurement system and an emergency power source.

The NV-GPS2-LOCO recorder is a device dedicated to monitoring the operating parameters of a locomotive engine.

In the standard dedicated version, the device provides data from GPS (time, position, speed, direction) and additionally from external sensors:

- water temperature;
- oil temperature;
- oil pressure;
- fuel level from digital fuel probes (upper tank, lower tank, optional tank additional);
- engine speed;
- the working status of the first and second fuel pumps;
- webasto coolant heater working status;
- measuring the current from the traction motor;
- measuring the voltage of the main generator.

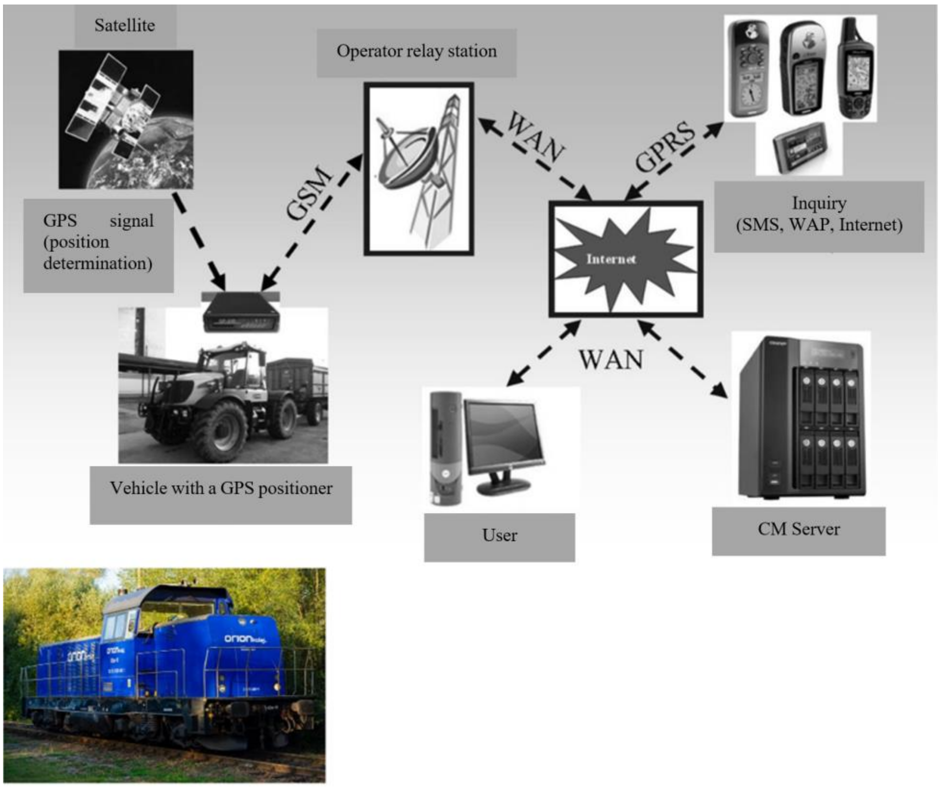

Figure 1. Block layout of the GPS monitoring system.
Source: „Wykorzystanie satelitarnego systemu GPS do monitorowania parametrów pracy pojazdów i maszyn w rolnictwie", P. Komarnicki, 2011, *Inżynieria Rolnicza, 4*(129).

The whole is powered from the locomotive's batteries (110V DC input), it has a charging system 24V buffer battery, the inputs are galvanically isolated from the locomotive installation. The standard software of the NaviCar vehicle monitoring system with a slightly more extensive reporting part is used for visualization – this allows you to detect undesirable situations, e.g. low oil pressure, incorrect start and stop of the internal combustion engine, long-term operation in gear idle and many others. The NaviCar software, thanks to its universality, allows you to defining many conditions and events – an example of the definition of "bad start" is the detection of an event when any of the conditions is met: water temperature lower than 36°C, oil temperature lower than 26°C, oil pressure lower than 0.08 MPa, or pre-priming pump detection of the presented event is of great importance in the event of a failure of the piston-connecting rod system of the engine seizing, in order to know the cause and persons responsible, and in the case of the warranty period of the vehicle, an allocation of repair costs.

The NAVI-CAR 2 system consists of:

- GPS-NV-GPS2-LOCO signal recorder;
- Quad-band GSM module (GPRS, SMS, audio);
- 66 channel GPS receiver;
- internal GPS antenna;
- external GPS antenna (optional);
- 1 MB non-volatile memory (e.g. to store 50,000 GPS data records);
- sensors and transducers of operating parameters.

The ORION Kolej company equips the locomotives it operates with recorders for monitoring operating parameters, as well as vehicles that are in the warranty period after periodic repairs (NaviSoft technical materials navisoft.pl/elektronika).

3. Characteristics of the compared vehicles

The first locomotive subjected to observation is the SM42 series locomotive, side number 2600. This locomotive, produced in the years 1960-1990 of the 20th century, has been used to this day, it is equipped with a power generator with an a8C22 engine manufactured by HCP Poznań (Figure 2). SM 42 locomotives are the most numerous series of diesel locomotives used in Poland by railway carriers as well as operators of railway sidings in industrial plants.

Figure 2. A8C22 internal combustion engine.
Source: own elaboration.

It is a shunting diesel locomotive with an electric transmission with the Bo Be" axle system and the following traction parameters (Figure 3):

- Locomotive power – 554 kW (800 HP);
- Vehicle weight – 74 t;
- max. speed 90 km/h;
- Traction force – 228 kN;
- Combustion engine type HCP a8C22-8 V, cat. 50%;
- Engine speed – 1000 rpm;
- Specific fuel consumption – 225 g/kWh;
- Piston diameter – 220 mm;
- Piston stroke – 270 mm;
- Aggregate weight – 7,400 kg + 4,000 kg – 12,000 kg.

Figure 3. Diesel locomotive series SM42 (6D/6Da).
Source: own elaboration.

Figure 4. Modernized 6Dm-01 locomotive.
Source: own elaboration.

The second vehicle is the SM42 locomotive comprehensively modernized by the "ORION Kolej" company. This modernization version is marked with the 6Dm type (Figure 4) with an asynchronous main generator, replacing the control system with microprocessor ones, changing the equipment of the driver's cab and engine compartments.

3.1. Scope of modernization of the 6Dm vehicle

The entire mechanical part of the locomotive was modernized. The elements used, subjected to major repair, are a completely rebuilt locomotive mainstay, 1LNa bogies and traction motors. A completely new construction of the driver's cabin, machinery compartments housing the power generator and auxiliary devices was made. The power generator consists of a CAT C-27 combustion engine (Figure 5), a main generator and an auxiliary generator. The locomotive has a microprocessor control, anti-skid system, board layout brake, diesel-electric transmission of the locomotive alternating current – direct current. Built-in traffic safety devices include the following systems:

- Active deadman system;
- SHP automatic train braking system with Radio-Stop system;
- Fire detection and extinguishing system;
- Radio communication with the GMS-R system;
- TTV monitoring system.

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

The locomotive has air-conditioning of the driver's cabin, social equipment, which includes a refrigerator, electric heating plate, washbasin, a spacious wardrobe, a diagnostic monitor, spring-loaded parking brake.

Figure 5. The modernized SM42 (6Dm) locomotive during homologation tests.
Source: own elaboration.

3.2. Driver's cabin

The structure of the driver's cab is made of steel profiles and is placed on the locomotive's underframe with four metal-rubber elements. This solution eliminates vibrations from driving and the internal combustion engine. The entrance to the cabin leads from the platforms and is located on both sides of the vehicle. The width of the cabin has been increased. The side walls feature modern pop-up and sliding windows with glued-in panes. The windshields are equipped with a heating system. Thermal and acoustic insulation in the form of non-combustible mineral wool has been built in the cavities of the walls and ceiling of the cabin. All internal walls, ceiling and both desks are lined with aesthetic elements (panels) made of non-flammable polyester resins (Figure 6).

Figure 6. The interior of the 6Dm ORION Kolej driver's cab.
Source: own elaboration.

The driver's cab is equipped with two ergonomic driver's desks, which enable driving in a given direction, as well as, after folding the seat, operation from a standing position, which is required during manoeuvres.

Figure 7. Desktop of the 6Dm 01 locomotive.
Source: own elaboration.

A diagnostic panel, a drive and brake controller, and pressure gauges have been mounted on the dashboards braking system, a radiotelephone and buttons and devices necessary to operate the locomotive. By The design of the desktop was guided by the principle to place only the necessary devices on the desktop, and not them the location was in accordance with the principles of ergonomics (Figure 7).

In the driver's cab there is also a low-voltage electrical cabinet panel, a fuel consumption monitoring terminal. The locomotive can be driven by one person switches for operating the internal combustion engine, parking brake, anti-reflection switch were installed.

3.3. Generator

The power generator installed on the locomotive consists of a C27 C27 diesel engine, an EMIT GTds 400 M4C-3 asynchronous main generator, and a 3x400 V auxiliary generator rubber on the locomotive underframe four-stroke, turbocharged it's the engine. Is CAT internal combustion Engine C27 controlled fuel injection, using with unit injectors. Engine electronically complies with air cooling STAGE IIIA emissions, and its fuel consumption is 198 g/kWh. The main generator is an alternating current machine with two bearings connected by a flange to the housing of the internal combustion engine's flywheel. An auxiliary generator is mounted on the generator standards driven by a belt drive (Figure 8). Diagram of the power generator of the modernized 6Dm locomotive.

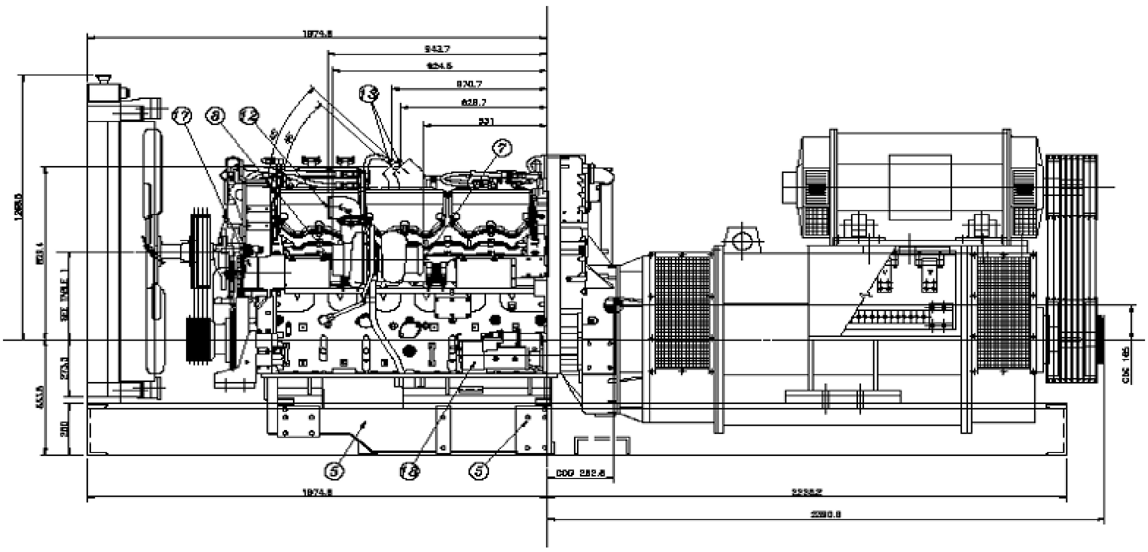

Figure 8. Diagram of the power generator of the modernized 6Dm locomotive.
Source: own elaboration.

3.4. 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 regulator of the internal combustion engine, automatically switches on the traction motor shunting system after exceeding the set driving parameters, performs automatic control and elimination of wheel slip, performs operation of the systems protecting the operation of the locomotive and the internal combustion engine.

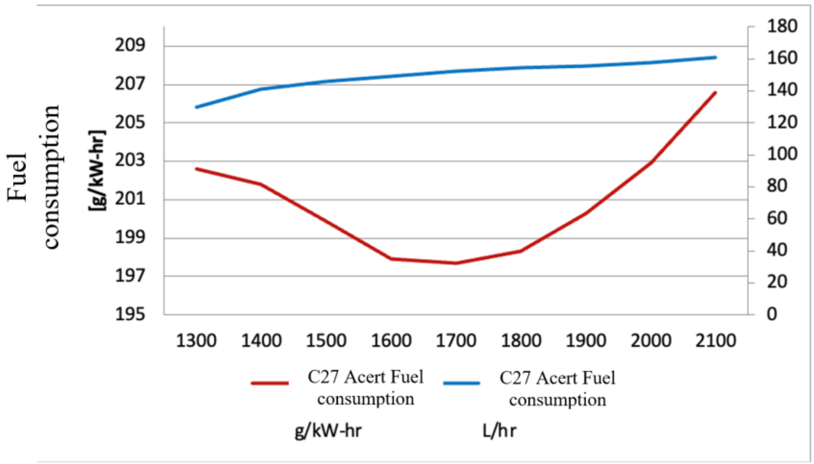

Figure 9. Chart of fuel consumption of the CAT C27 internal combustion engine.
Source: own elaboration.

4. The course of comparative vehicle tests

A comparative study of fuel consumption was carried out on two diesel locomotives – the first of the SM42 2600 series – a vehicle without modernization, the second is a modernized 6Dm-01 locomotive. The vehicles were operated at the marshalling yard of the Northern Port in Gdańsk – 6Dm-01 and at the port of Gdynia. Working conditions involving maneuvers when assembling freight trains, on the same horizontal profile within the marshalling yard tracks.

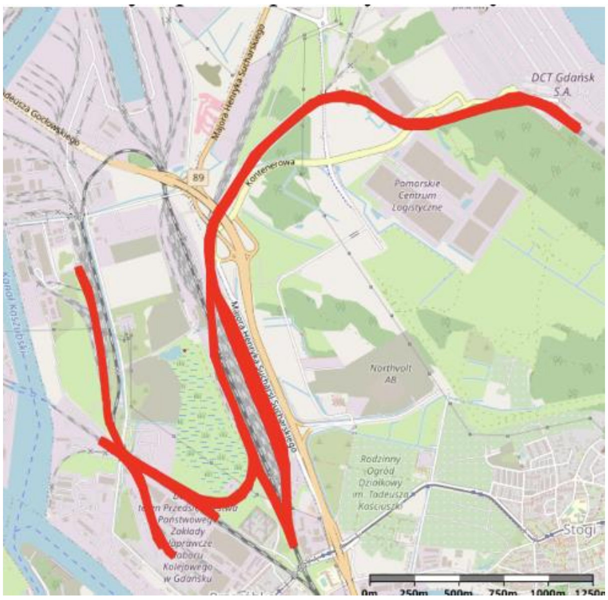

Figure 10. View of the locomotive working time in the GPS NAVI-CAR system.
Source: own elaboration.

When comparing, the work of vehicles was averaged over one month by checking and comparing working (driving) times, stopping times, fuel consumption. In everyday work, it is impossible to perfectly match and compare work cycles – driving, stopping, shunting work, but in the long term, e.g. one month, you can approximately estimate the consumption and costs of vehicle operation (Figures 10-11).

Figure 11. An example of the vehicle's workflow based on the NAVI-CAR program.
Source: own elaboration.

The tables below contain a summary of work in individual weeks of May 2023 for the modernized 6Dm-01 locomotive (Table 1) and the SM42 2600 locomotive without modernization (Table 2).

For comparison, in May 2023, the SM42 2600 locomotive covered a distance of 624 kilometers, consuming 3,544 liters of fuel, while the 6Dm-01 locomotive, for a distance of 625 kilometers, consumed 1,982 liters of fuel, which is about 30% savings on fuel costs per month.

Table 1
Summary of the operation of the 6Dm -01 locomotive saved in the GPS NAVI-CAR system

Summary of fuel consumption during shunting work for the modernized 6Dm-01 locomotive				
	Date May 01-07, 2023	**Date May 08-14, 2023**	**Date May 15-23, 2023**	**comments:**
Stops [h]	147	184	190	
Ride	20.11	8	25	
Distance traveled	228.7	77	318	
Fuel Burned [1]	803	295	884	
Fuel consumption [1/100km]	351	382	278	
Average speed	17.1	12	16	
max. speed	58	30	46	

Source: own elaboration.

Table 2
Summary of operation of the SM42-2600 locomotive saved in the GPS NAVI-CAR system

Summary of fuel consumption during shunting work for the modernized 6Dm-01 locomotive				
	Date May 01-07, 2023	**Date May 08-14, 2023**	**Date May 15-23, 2023**	**comments:**
Stops [h]	140	174	184	
Ride	27	17	31	
Distance traveled	343	226	346	
Fuel Burned [1]	1,128	1,010	1,406	
Fuel consumption [1/100km]	328	446	405	
Average speed	14.6	15	12	
max. speed	45	53	40	

Source: own elaboration.

5. Conclusions

The comparison of fuel consumption and operating costs of a modernized locomotive presented in this article in relation to a vehicle not subjected to modernization in a broader sense, not only showing fuel consumption, but also oil costs and costs of ongoing maintenance, clearly indicates the direction that operators of shunting diesel locomotives should take. These solutions show the way to be followed, the aim of which is to eliminate old fuel--consuming and not ecological railway traction vehicles (Szkoda, 2011).

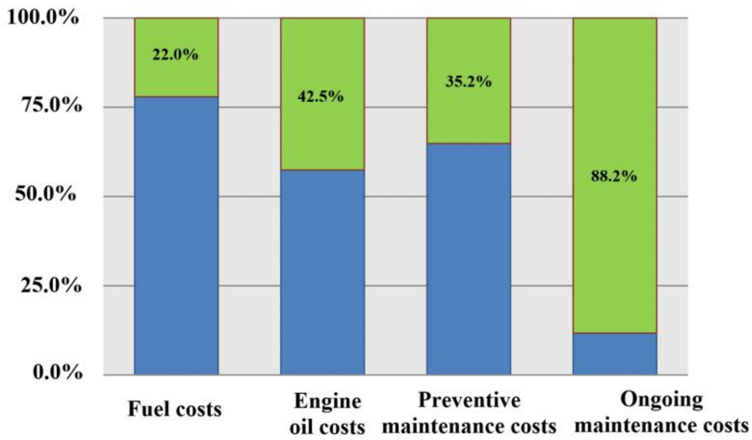

Figure 12. Savings of selected parameters of the 6Dm locomotive after modernization.
Source: own elaboration.

Modernization of the vehicle in the 6Dm variant is related not only to only in the replacement of the power generator, which improves fuel and oil consumption and reduces the emission of pollutants to the environment, but also in changing the shape of the external appearance of the vehicle, which improves the safety of maneuvering works by – improving visibility, ergonomics of the service staff – by eliminating vibrations, social equipment of the driver's cabin, on-board diagnostics. In addition, when using the GPS system on locomotives, any deviation from the average of the accepted standard may be a signal for undesirable seizure interventions to eliminate faults in locomotive systems, increased wear and even fuel consumption.

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Section III

New challenges, technologies and solutions innovations in production engineering

Concept for implementing the 5S system – case study

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Abstract: Modern companies operate in a highly volatile environment. To grow, they need to constantly improve their operations and adapt to dynamically changing conditions. The 5S system is one of the basic tools of lean management and is one of the best workplace organization practices. It is based on standardization and constant attention to the workplace. The aim of the study was to analyze the stages of implementing the 5S system in a selected area of a manufacturing enterprise. For the pilot implementation of the system, one of the production stages was selected, which is the assembly of door finishing components, according to a previously developed production order. In the course of the analysis, a 5S implementation strategy was developed, consisting of 6 stages: conducting training for employees; forming an implementation team; analyzing workstations; developing a layout; preparing health and safety boards; and implementing 5S. Implementation of the method with 5S in the organization required a high level of involvement of all employees at a relatively low financial cost. Its implementation brought tangible benefits in a short time. Work at the posts became comfortable for employees, better organized and more efficient. The analyzed case shows that the implementation of the 5S system also improves on the atmosphere at work. It creates rules for the organization of the enterprise and standards of work that increase productivity, and influences the provision of safe and ergonomic working conditions. It can also be seen as a foundation for the introduction of further improvements such as SMED, Kanban and TPM.
Key words: 5S system, lean manufacturing, production, workstation.

1. Introduction

Modern companies operate in a highly volatile environment. The development of companies therefore requires continuous improvement and adaptation to dynamically changing conditions. One method geared towards continuous improvement is the 5S method. It is mainly used to improve workplaces in production processes, although it is also applicable to other industries. The 5S method is the result of years of practice and experience of leading Japanese companies. It focuses on improving quality, productivity, work streamlining, safety and management, which can contribute to solving many work organisation problems. Used effectively, it can become an important part of the visual inspection process that helps implement lean manufacturing principles. It contributes to eliminating waste, streamlining processes and reducing unnecessary activities. The method identifies many hitherto unnoticed and hidden problems in the company. More narrowly, it refers to standards for keeping the workplace tidy (Czerska, 2014; Iranmanesh, Zailani, Hyun, Ali, Kim, 2019; Łazicki, 2010; Pacana, Gazda, Wołoszyn, 2014).

The 5S method is based on five principles, the first letters of which are the origin of the method's name (Wolniak, 2013):

1. Sorting (jap. seiri) – it consists in organizing items in the workplace and eliminating the unnecessary ones.
2. Systematics (jap. seiton) – it consists in arranging tools or components in a way that makes it easy to do the job. Everything should have its place, and the tools and items that are used most often should be easily accessible.

3. Cleaning (jap. seiso) – it involves keeping the workplace clean and tidy. Regular cleaning helps to keep things tidy and minimise the risk of accidents.
4. Standardisation (jap. seiketsu) – it involves the introduction of standards and procedures for order and work. Standardisation ensures that every employee knows what to do and how to do it.
5. Self-discipline (jap. shitsuke) – it consists in maintaining and continuously improving the standards introduced. It requires the commitment and responsibility of each employee for the state of their workplace.

2. The process of implementing the 5S method in a selected company – case study

The aim of the research was to analyse stages of implementing the 5S system in a selected area of a production company.

The analysed company is located in the Małopolskie Voivodeship. It is classified as a large enterprise in the manufacturing sector. The company manufactures products used in the construction industry, which are sold throughout Europe. All of the company's products have mandatory, industry-specific certificates. In addition, the company has implemented quality and occupational health and safety management systems in accordance with ISO 9001:2015 and ISO 45001:2018.

Table 1
Stages of 5S implementation

No.	Implementation stage	Purpose of each stage
1.	Conducting employee training on the 5S system.	Increasing staff awareness, encouraging cooperation.
2.	Creation of an implementation team.	Appointment of a brigade of staff responsible for implementing the system.
3.	Conducting a job analysis.	Locating steps or processes that generate any kind of waste.
4.	Layout development.	Workplace visualisation after the introduction of the 5S system.
5.	Preparation of the occupational health and safety signs.	Increasing safety.
6.	Introduction of the 5S.	Implementation of the 5 pillars: selection, systematics, cleaning, standardisation, self-discipline.

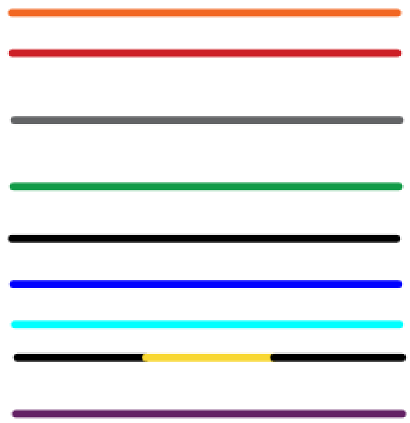
Source: *Projekt koncepcyjny wdrożenia systemu 5S w wybranym przedsiębiorstwie produkcyjnym*, A. Bugara, 2023, praca dyplomowa. Wydział Nauk Inżynieryjnych ANS w Nowym Sączu.

Based on the audit, it was concluded that there was a need for changes in the company to improve and maintain good organisation of workstations, according to the 5S method. For the pilot implementation of the system, one of the production stages was selected, which is the assembly of door finishing components, according to a previously developed production order. In the course of the analysis, a 5S implementation strategy was developed, consisting of six stages (Table 1).

In the first stage of implementation, as part of the planned training, employees were introduced to the 5S method. The training was extended to all employees of the analysed area.

In the next step, an implementation team was formed to pilot the introduction of the 5S system. This was followed by an analysis of the workstations in the selected department. A layout was drawn up of the production hall covered by the implemented system (Figure 1).

Legend to Figure 1



Colour	Objects and places of marking
	Doors and frames for further production
	Waste, space for non-compliant product
	Workbenches, rotating trolleys, building wall imitation frame
	Raw material racks and finished product racks
	Product awaiting further processing
	Finished product
	OHS board
	Dangerous places
	Cleanliness corner

In line with the implementation strategy, the next stage involved the design of occupational health and safety boards, i.e. places where all relevant information and items related to safety at the workplace would be located. It was planned to develop three pieces of boards, which were placed on the production floor in easily accessible places so that every worker could access them (Figures 1 and 2).

The boards are made of stainless steel. It is engraved with the name of the department concerned. It features, among other things, a first-aid kit, equipped with the necessary first-aid supplies; a fire extinguisher; and a cabinet for chemical safety data sheets and the necessary instructions for the equipment used by the workers.

The process of the actual implementation of the system took place after previous observations and interviews with employees performing specific activities in the production area under analysis. This was in order to identify wastage at production sites.

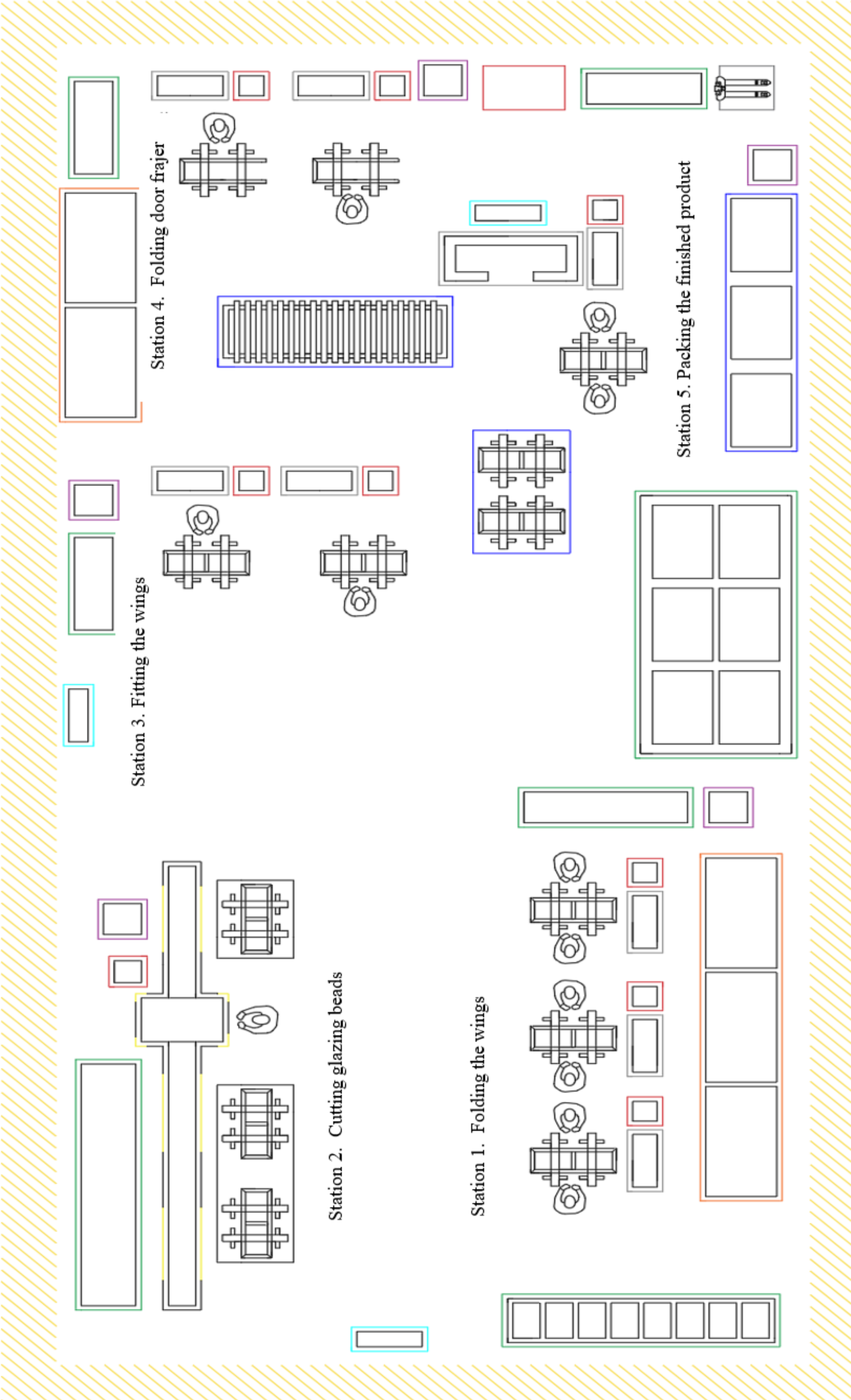


Figure 1. Layout of the production hall.
Source: *Projekt koncepcyjny wdrożenia systemu 5S w wybranym przedsiębiorstwie produkcyjnym*, A. Bugara, 2023, praca dyplomowa, Wydział Nauk Inżynieryjnych ANS w Nowym Sączu.

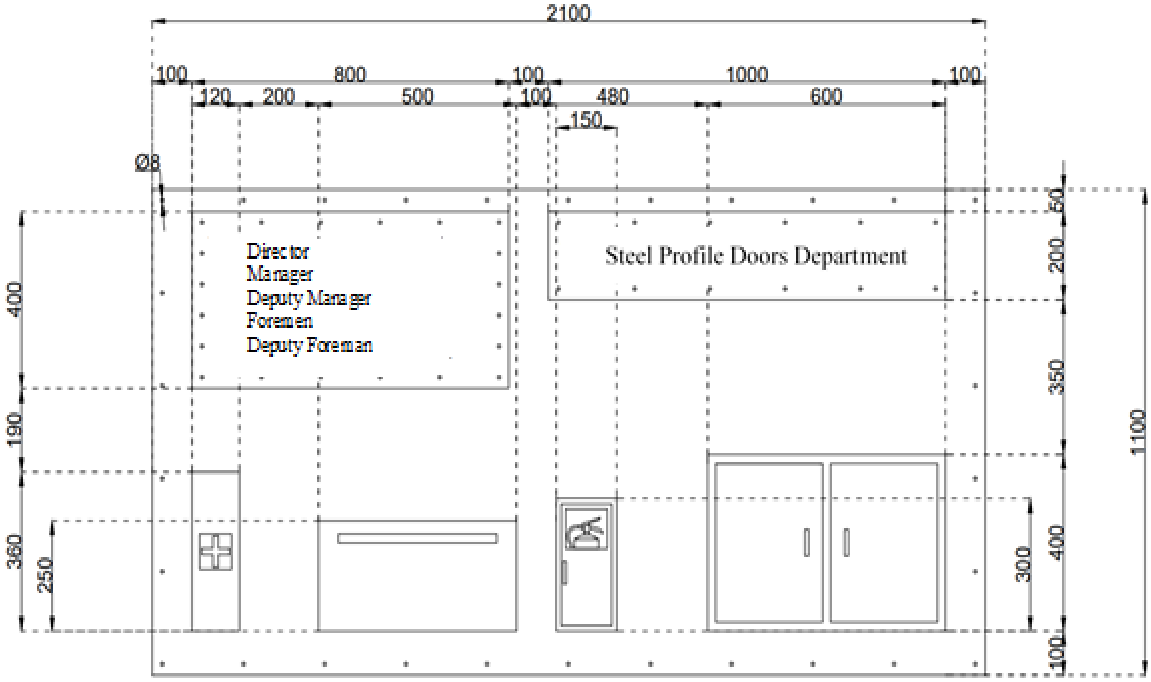


Figure 2. BHP Table.
Source: *Projekt koncepcyjny wdrożenia systemu 5S w wybranym przedsiębiorstwie produkcyjnym*, A. Bugara, 2023, praca dyplomowa, Wydział Nauk Inżynieryjnych ANS w Nowym Sączu.

The first step in introducing the system was *selection*. At this stage, all unnecessary items were identified and removed from workstations. The stage was aimed at completely eliminating wasted places and the working time spent searching for necessary tools. It was performed according to the so-called 'red-labelling strategy' (Czajkowska, 2018). The design of the adopted label is shown in Figure 3.

5 S Red label	
Item type: ☐ Tool ☐ Operating component ☐ Raw material ☐ Chemicals	Date: ………………………………. Signature of employee: ………………………………………. **Decision:**
Place of origin of the item: ☐ Workstation 1 ☐ Workstation 4 ☐ Workstation 2 ☐ Workstation 5 ☐ Workstation 3	☐ Leave it in place ☐ Transfer to a warehouse Signature of the supervisor: …………………………………………

Figure 3. Red label design.
Source: *Projekt koncepcyjny wdrożenia systemu 5S w wybranym przedsiębiorstwie produkcyjnym*, A. Bugara, 2023, praca dyplomowa, Wydział Nauk Inżynieryjnych ANS w Nowym Sączu.

The selection stage allowed the first, noticeable results to be achieved in a short time with a minimum of expense.

The second stage was systematics. The team analysed the way in which the workstations were laid out and arranged so that they created convenient working conditions. The process started with the marking of the workstations on the shop floor using coloured floor tapes. This was followed by the development and implementation of an optimum layout for the workstations, ensuring that the most frequently used items were located closest to the worker and that there was easy access to all other items used by the workers. The items will be put away by the workers at the end of their work in a designated place. The storage areas have been labelled. Labelling of the storage areas for the materials and semi-finished products used in the process has also been developed (Figure 4).

Figure 4. Label designating the storage area for an assembly component.
Source: *Projekt koncepcyjny wdrożenia systemu 5S w wybranym przedsiębiorstwie produkcyjnym*, A. Bugara, 2023, praca dyplomowa, Wydział Nauk Inżynieryjnych ANS w Nowym Sączu.

The application of this solution had a direct, noticeable impact on the speed of operations, thereby reducing the time of the assembly process. As part of this stage, minimum and maximum stocks were additionally established in connection with deliveries from the warehouse. When raw materials are delivered daily, the minimum stock should be one day's requirement and the maximum stock should be two days' requirement. An example of a racking marking pattern is shown in Figure 5, where a green line indicates that the racking has a 1-day demand and a red line indicates a 2-day demand.

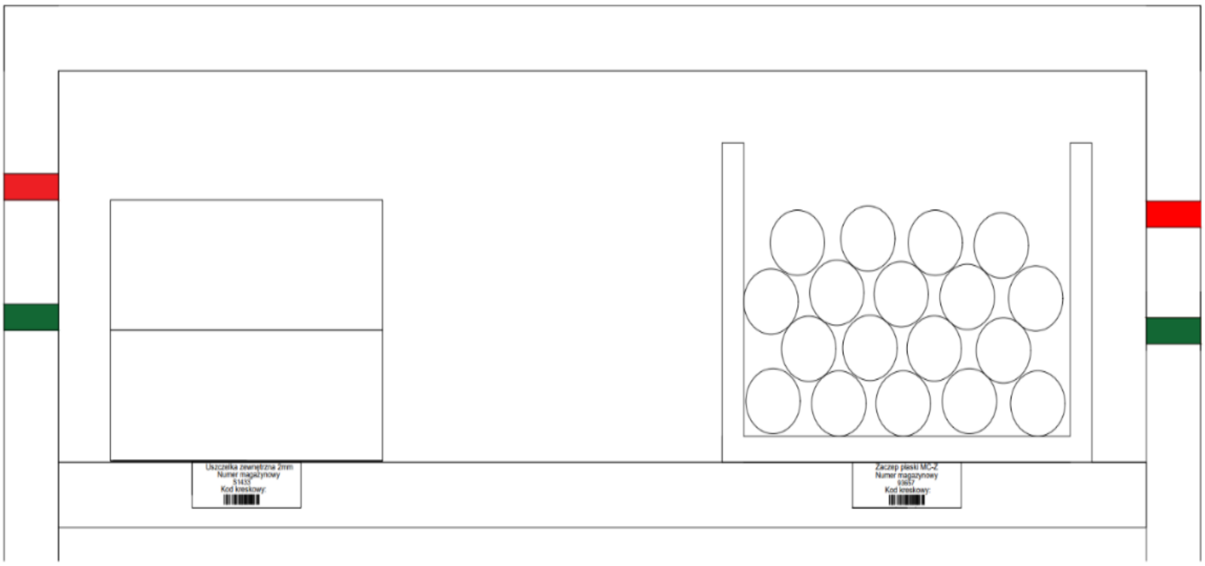


Figure 5. Draft labeling of quantities of raw materials on the shelf.
Source: *Projekt koncepcyjny wdrożenia systemu 5S w wybranym przedsiębiorstwie produkcyjnym*, A. Bugara, 2023, praca dyplomowa, Wydział Nauk Inżynieryjnych ANS w Nowym Sączu.

It is worth emphasising that the systematisation stage is one of the most important steps in the implementation of the 5S method. In the main, it is this stage that determines how much the analysed processes can be improved and how much time can be saved.

Implementing the third stage (cleaning) required dividing the hall into zones, according to previously organised workstations. The employees who work there are responsible for maintaining the cleanliness of the separated areas.

The areas that need cleaning were then defined in separate zones and the methods for doing so were selected. This is an important element of the third stage, as it means facilitating cleanliness through regular cleaning and creating a sense of duty in the worker. A cleaning plan was drawn up for each area. An example of a plan for workstation 2 is shown in Figure 6.

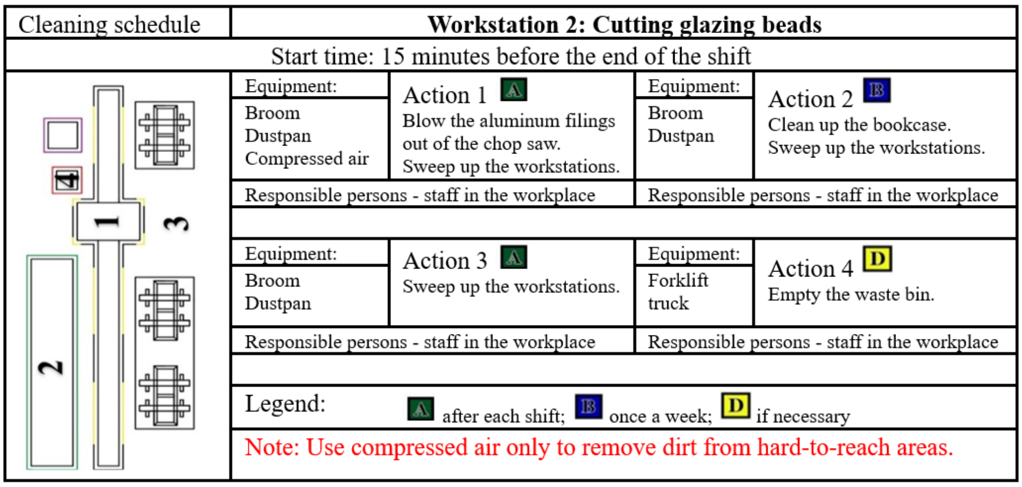


Figure 6. Cleaning plan for stand 2.

Source: *Projekt koncepcyjny wdrożenia systemu 5S w wybranym przedsiębiorstwie produkcyjnym*, A. Bugara, 2023, praca dyplomowa, Wydział Nauk Inżynieryjnych ANS w Nowym Sączu.

In addition, a so-called 'cleanliness corner' was placed at each station (Figure 7).

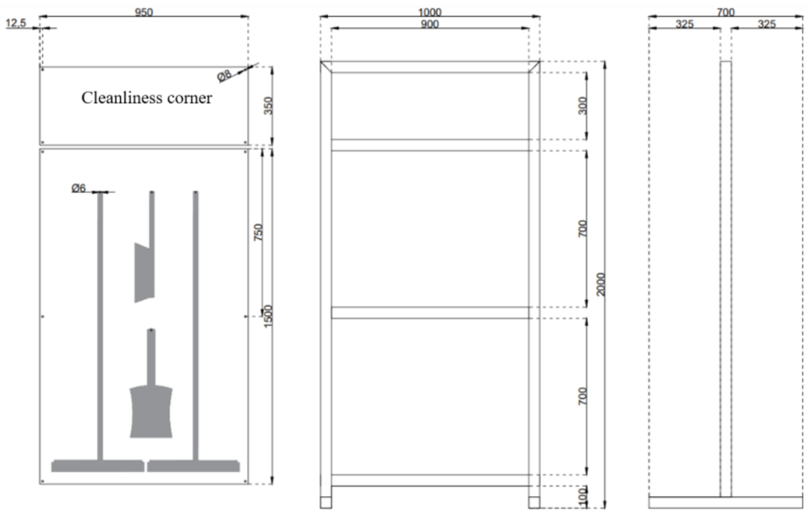


Figure 7. Design of the cleanliness corner.

Source: *Projekt koncepcyjny wdrożenia systemu 5S w wybranym przedsiębiorstwie produkcyjnym*, A. Bugara, 2023, praca dyplomowa, Wydział Nauk Inżynieryjnych ANS w Nowym Sączu.

It is worth noting that proper attention to tidiness at the workplace also contributes to identifying the causes of failure damage. Undoubtedly, the introduction of cleaning requirements, as a result of the implementation of the 5S system, is a guarantee of keeping the workplace in full readiness.

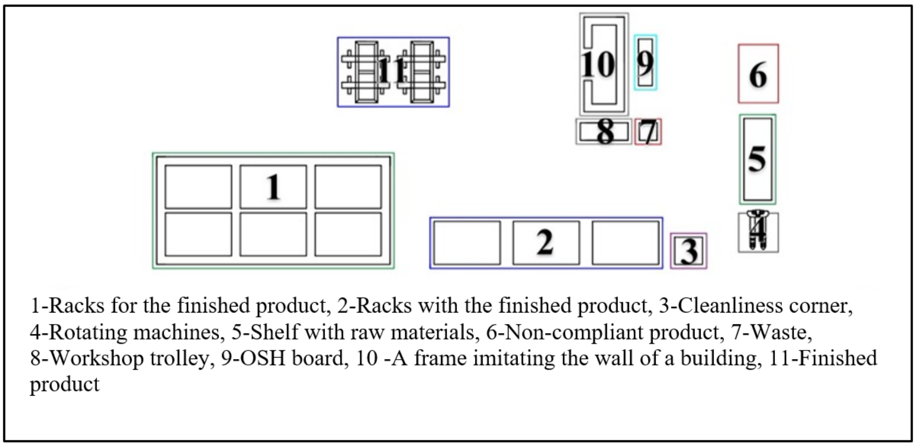


Figure 8. Model standard for the location of objects on the production floor.
Source: *Projekt koncepcyjny wdrożenia systemu 5S w wybranym przedsiębiorstwie produkcyjnym*, A. Bugara, 2023, praca dyplomowa, Wydział Nauk Inżynieryjnych ANS w Nowym Sączu.

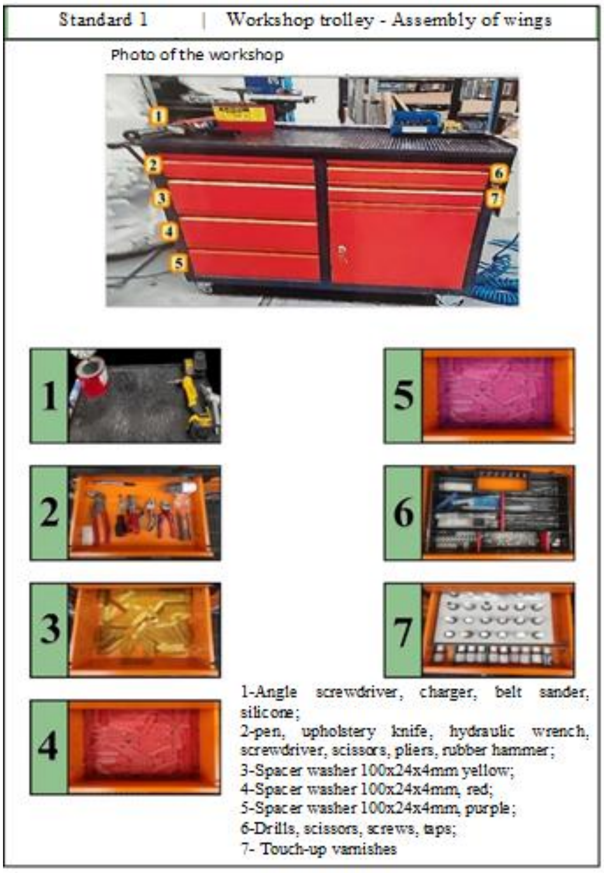


Figure 9. Model equipment standard for the workplace.
Source: *Projekt koncepcyjny wdrożenia systemu 5S w wybranym przedsiębiorstwie produkcyjnym*, A. Bugara, 2023, praca dyplomowa, Wydział Nauk Inżynieryjnych ANS w Nowym Sączu.

The fourth stage introduced standards, i.e. instructions specifying compliance with the changes previously introduced. *Standardisation* is necessary to maintain the state achieved after the introduction of the first three stages. From a formal point of view, it is considered to be the most complicated point in the implementation of the 5S method. The assumption is that the standards for the arrangement and labelling of tools, materials and workplace equipment must be generally known and consistent within the process. They should be simple, clear and easy for employees to understand. Figure 8 shows the layout standard for the selected workstation and Figure 9 shows an example of the equipment standard for the door leaf picking workstation.

The final stage of introducing the 5S system in the company was *self-discipline*. This stage was aimed at developing among employees the habits necessary to comply with the implemented solutions, as well as the ability to work according to the standards introduced. The above helps to prevent employees from falling back into old habits.

In order to implement self-discipline, it was necessary to set up teams to monitor and evaluate the maintenance of standards at individual workplaces. Figure 10 shows the evaluation sheet developed. After the audit assessment, the results are presented to the employees and discussed in detail. The results are posted on an ongoing basis on the Health and Safety board. It is assumed that an assessment is considered positive if the number of points obtained is greater than 45%.

3. Conclusions

The implementation of the 5S method in the organisation required a high level of commitment from all employees at a relatively low financial cost. Its implementation brought tangible benefits in a short time. Work at the workstations became comfortable for employees, better organised and more efficient. Noticeable benefits include:

- improving the ergonomics of workplaces;
- tidying up of workplaces and work tools, thus avoiding unnecessary physical exertion by workers and reducing the likelihood of accidents;
- better organisation of workplaces by, inter alia, eliminating the waste of time associated with the search for items needed to do a job;
- reduced or avoided expenses related to the replenishment of lost or damaged tools and materials;
- better visibility of stock problems and therefore the ability to react quickly to any deviations;
- an increased sense of belonging among employees through their involvement in the implementation of the 5S method at their workstations;
- strengthening pro-quality behaviour and proactive attitudes of employees;
- improved communication between employees at vertical and horizontal levels.

5S Zone Audit

Department/Zone:
Yes/True = 1 • No/False = 0
0-2: Red, Unacceptable
3-4: Yellow, Progress Being Made
5: Green, Acceptable

	Distinguish between what is needed and not needed		
Sort	Only needed equipment, tools, furniture, etc., are present	0	0
	Only needed items are on walls, bulletin boards, etc.	0	
	No items are present in aisleways, stairways, corners, etc.	0	
	Only needed inventory, supplies, parts, or materials are present	0	
	No safety hazards, (water, oil, chemical, machines, etc.) exist	0	
	A place for everything and everything in its place		
Straighten	Correct location for items are obvious	1	5
	Items are in their correct places	1	
	Aisleways, workplaces, and equipment have designated locations	1	
	It is evident that items are put away immediately after use	1	
	Height and quantity limits have been designated	1	
	Clean, and look for ways to keep clean and organized		
Shine	Floors, walls, stairs, and surfaces are free of dirt, oil, and grease	1	5
	Equipment is kept clean and free of dirt, oil, and grease	1	
	Cleaning materials are marked and easily accessible	1	
	Lines, labels, signs, etc., are clean and in good repair	1	
	Other cleaning problems of any kind have been addressed	1	
	Maintain and monitor the first three cateogries		
Standardize	Necessary information is visible and meets visual workplace standards	1	5
	All standards are visible	1	
	Checklists exist for all cleaning tasks with daily manager review	1	
	All quantities and limits are easily recognizable	1	
	All commonly used items are within reach of the operation	1	
	Stick to the rules		
Sustain	5S checklist is current and signed off	1	5
	An opportunity sheet is posted and tasks assigned and dated	1	
	Personal belongings are stored aware from the work area	1	
	Job aids are available and up to date	1	
	Weekly manager review signed off	1	

Comments:

Audit Completed by:
Date:

Overall Rating: 4

Figure 10. Assessment sheet.
Source: *Projekt koncepcyjny wdrożenia systemu 5S w wybranym przedsiębiorstwie produkcyjnym*, A. Bugara, 2023, praca dyplomowa, Wydział Nauk Inżynieryjnych ANS w Nowym Sączu.

It should also be stressed that, in practice, the implementation of the 5S method encounters a number of problems that may constitute a barrier to its operation in the enterprise. One of the most common is the potential resistance of employees, resulting from the top-down imposition of the system, without consultation with employees resulting in a lack of understanding of the purpose and essence of this method. Additional problems may also be caused by previous habits, especially in employees with many years of experience Employee resistance may also be related to employees' mistaken perception of audit activities as increased control on the job.

Given the benefits and difficulties of implementing the 5S system outlined above, it is important to ensure proper communication with employees at every stage of the implementation and maintenance of the system and to keep them informed of results and changes.

The 5S system also provides benefits that are difficult to quantify directly, as the introduction of the system contributes to the development of a proactive culture of work improvement.

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Devices supporting the work of the organist

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Abstract: Modern pipe organs include many solutions to make the organist's work easier, such as supporting mechanical playing traction or facilitating when registration the instrument. Nowadays, mechatronic devices are used for this purpose, with the help of which the timbre of the instrument can be changed quickly and easily. The paper will present the evolution of devices supporting the organist's work from simple mechanical and pneumatic solutions to complex mechatronic systems.
Key words: electromagnets, abstracts, coupling keyboards action.

1. Introduction

The pipe organ is a musical instrument of extraordinarily broad capabilities and enormous variety, found around the world in countless versions, and is a tool for both soloists and accompanists (Kądziołka, Kowalski, Mońko, 2021). Master musicians with the organ in mind wrote works maintained in forms ranging from ascetic to highly complex – symphonic.

Nowadays, organs have settled permanently mainly in churches and concert halls, although initially they were used only for entertainment purposes – they are not only one of the most valuable cultural treasures having its origins already in antiquity, but are also a wonderful work of technical thought serving the arts. Their peculiarities and needs arising from musical stylistics over the centuries, forced, as it were, technological progress in the field of organbuilding. Cultural or industrial evolution /Industry 4.0/ has also reached music, so further changes are also to be expected in the principles of instrument building, as well as organ building.

Of the vast number of musical instruments invented and improved over the years, the pipe organ has earned the laudable nickname of "King" (Sumner, 1962). This term is, of course, fully justified as no other instrument has so many sounding elements and possesses such a wide range of sounds both in terms of scale span and multiplicity of timbres.

There is so much diversity in this field, both in terms of sound and technological solutions, that it is impossible to precisely classify this instrument. It is certainly an aerophone, but it also happens to have string voices, percussion voices, playing bells which makes it an "orchestra" controlled by a single musician (Audsley, 1965).

Such richness in the sound of the organ, with the concentration of operation in one place for only one person playing, poses a very great challenge to organ builders, hence for many centuries there have been continuous technological developments leading to the gradual evaluation of organ mechanisms and making the instrument easier to operate by the performer (Kądziołka, Kowalski, Mońko, 2021). For this reason, since the appearance of organs in history, the most up-to-date scientific advances could be found in newly built instruments in each era. This process is also observed in the present day, where the achievements of the 4th industrial revolution as well as bio-inspiration are used in organs (Ruszaj, 2015).

Nowadays, mechatronic devices are commonly installed in organs and are an indispensable form of assistance for organists, they are helpful in the proper preparation of the air, are used to reduce the force of the fingers on the keys /traction assist/, or enable the rapid change of the instrument's registration during the performance of songs (setzer), as well as, with the help of a radio path, enable the placement of the counter anywhere in the church or concert hall/wireless counter (Kądziołka, Kowalski, Mońko, 2021).

2. Historical development of devices to support the organist's work

As you know, the proper preparation of air in the organ is very important. Too little pressure causes muffled sound, and lack of proper tuning of the instrument. In turn, too high a pressure causes the voice produced by the pipe to become shrill, the instrument also in this case loses its tuning.

The bellows are responsible for the proper maintenance of pressure. Bellows should be designed so that they can supply the necessary amount of air when playing in unison or chords on one voice, on several voices or on all voices. An organ may have one common bellows for all tone units.

In larger organs, there are usually several: each Manual and Pedal has a separate bellows. As a general rule, each bellows should supply air at equal pressure (Wyszogrodzki, 2013).

The first organ models used bellows (pumps) that were moved by human muscle power to produce air. This solution was improved, which eventually resulted in the invention of the blower. As already mentioned, the pipe organ is an instrument that, in order to function properly, requires the supply of air at the correct – constant pressure. The electrical power requirements of the larger blowers supplying air to the organ start at a few kilowatts and go as high as about 450 kW (the Convention Hall organ in Atlantic City (NJ, USA) has seven blowers with a total output of about 600 horsepower, which comes out to about 447.5 kW). However, all this power of the blower unit is not necessary at all times. For most of the blower's operating time, its power is not used, and the unit constantly draws a large amount of electrical energy, converting it into compressed air, which is unfortunately wasted especially when the bellows is inflated, as the throttle closes and all excess pressure escapes through the overload valve (Figure 1). One hundred percent opening of the throttle happens very rarely, so the full power of the blower is not needed. In order to reduce the power consumption of the blower and thus reduce the operating costs of the instrument, a motor is used in the organ that allows stepless speed regulation by means of a so-called inverter, which, according to demand, regulates the frequency of the current phases and thus the bellows filling, which has a significant effect on reducing the power consumption to the amount necessary to maintain the correct blower speed at any given time. The inverter itself is controlled thanks to the air pressure sensor located in the bellows or by means of a mechanical bellows displacement sensor. The use of such a solution in the organ allows to adjust the speed of the blower necessary to maintain the correct output.

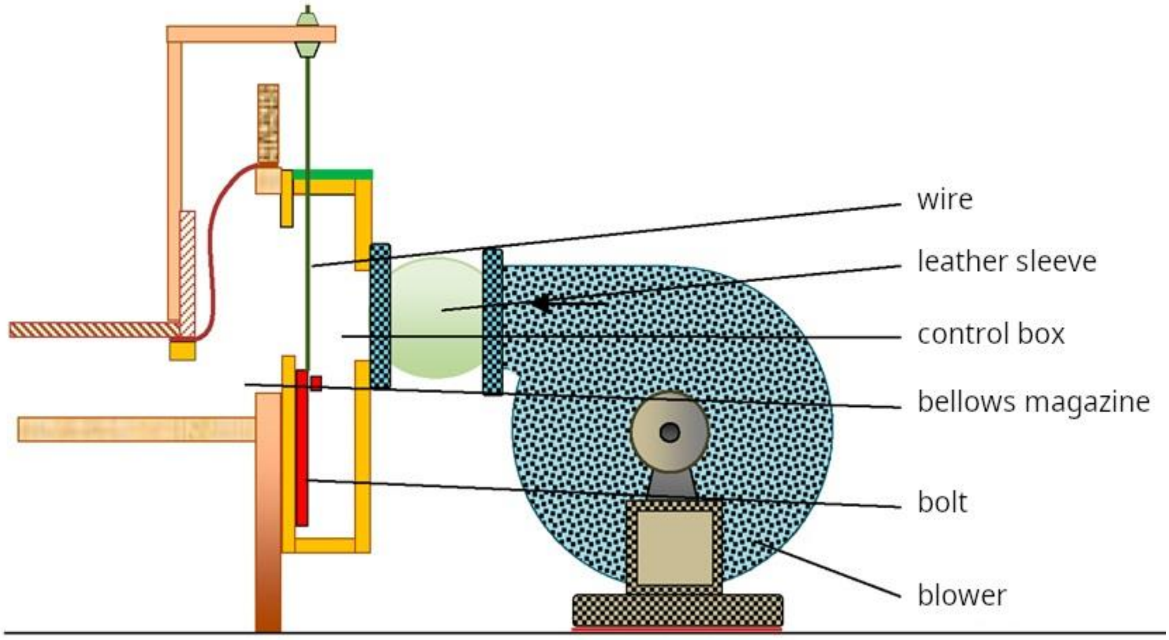

Figure 1. Organ blower including a damper that closes off air access to the bellows.
Source: *Budowa organów*, M. Wyszogrodzki, 2013, Lutomiersk: Salezjańskie Szkoły Muzyczne.

3. Electromagnetic support devices in organs

Organ builders have almost always kept technology up to date with advances in other scientific fields. Thanks to this, in the second half of the 19th century during the 3rd Industrial Revolution, with the development of mechanics and electricity, organs began to be equipped with some of the simplest elements of automation – electromagnets. This led to the proliferation of a new type of game tract called electromagnetic (Figure 2). This turned out to be an exceptionally simple solution compared to the complicated connections of abstracts, angles, multiple gears in organs with mechanical traction, or the imprecise, more complicated in design and rather failure-prone relays and pneumatic valves in pneumatic traction. This time, electric wires were used to transmit the signal between the keys and wind chest valves, instead of wooden ties or air. This gave organ builders tremendous opportunities to design the overall structure of the instrument, plus it meant that the playing table could be placed anywhere, as it had no direct mechanical connection to the rest of the organ. Also, there was no need to design and make mechanical gears resulting in the need to actuate the key with relatively high pressing forces. With a small amount of materials going into electromagnetic traction, instruments of enormous size could be built.

Electromagnets found their way into supporting intermandibular connections in mechanical traction (Figure 2), thus displacing the pneumatic Barker lever, which, despite being mounted in close proximity to the keyboard, had the disadvantage of delayed operation. This was particularly evident during fast play (Kądziołka, Kowalski, Mońko, 2021).

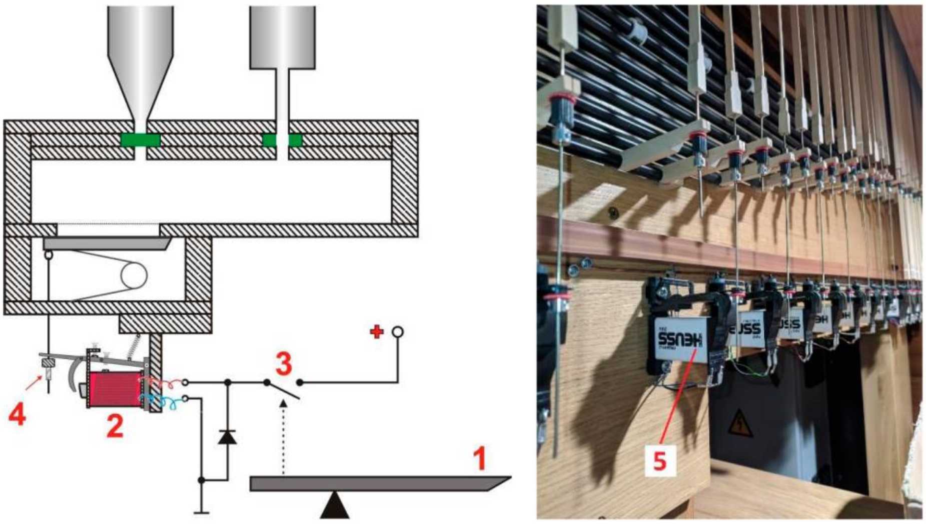

Figure 2. Electromagnetic tracture of play.
1 – key, 2 – electromagnet, 3 – key-operated electromagnet switch, 4 – flap valve linkage with control elements, 5 – electromagnetic support of mechanical tracture.

4. Study of the force acting on the key

In order to answer the question of whether mechanical traction support is necessary, an analysis was made of the force the organist must exert on the key in order to actuate the air valve located in the wind chest. As is well known, the use of mechanical traction causes the sound produced from the pipes to build up in a gradual manner with the so-called overblowing, this is especially important for connoisseurs of organ music.

Three pipe organs with mechanical traction located in the churches of the City of Nowy Sącz were selected for the study of the force of pressure on the key; the instruments in the other churches have electromagnetic traction.

The tests were carried out using an FH10 digital dynamometer to test tensile and compressive forces with a range of up to 10 N (Figure 3). By pressing a key with the FH10 dynamometer, the value of the force at which the correct voice came out of the instrument (full opening of the air valve in the instrument) was read. The results obtained are presented in Figure 4 (Kądziołka, Kowalski, 2014).

Figure 3. Digital dynamometer FH10.

Place of the instrument	Appearance of the instrument	Measured pressure force [N]
Organ in St. Lawrence Church Nowy Sącz – Biegonice. Year of production: 1909 r. Lack of support		2,0 – 5,5 N
Organ in St. Casimir's Church in Nowy Sacz Year of production: 2015 r. Lack of support		Manual 1 – 1,45 N Manual 2 – 1,40 N Manual 3 – 1,00 N 2 do 1 – 2,85 N 2 i 3 do 1 – 3,25 N
Organ of the Sanctuary of St. Rita in Nowy Sącz Year of production 2022. Electromagnetic support		Manual 1 – 1,50 N Manual 2 – 1,45 N Manual 3 – 1,50 N 1 in 2 – 1,50 N 3 in 2 – 1,55 N 1 i 3 in 2 – 1,60 N

Figure 4. Values of measured force with the FH10 dynamometer at the organ in Nowy Sącz.
Source: own elaboration.

5. Conclusions

Reviewing the development of pipe organs at the turn of history, it can be seen that the instrument underwent a number of upgrades. With the advent of electricity, organ builders increasingly began to introduce newer solutions in organ construction, finally replacing all mechanical traction – with electromagnets. For a certain period only organs with electromagnetic traction were built. Only when the problem of the so-called "dead" sound became apparent, there was a return to mechanical traction and possibly its support by electromagnets.

Analyzing the tests carried out on pipe organs with mechanical tracture in Nowy Sącz, shown in Figure 4, it should be noted that the highest pressing force, as much as 5.5 N in an extreme case, should be used in the Biegonice organ. This is explained by the fact that this instrument was built more than 100 years ago, admittedly it underwent a major renovation 15 years ago, but the renovation, as you can see, was inaccurate.

Reviewing the results of tests performed on the mechanical organ in St. Casimir's Church in Nowy Sącz, it should be noted that the least amount of pressure on an individual key to open the air valves in the wind chests is exerted by the organist when playing the individual manuals without connecting them to each other. As can also be seen, these forces do not increase very much even when all the manuals are connected together and amount to 3.25 N.

The organist playing the organ in the Shrine of St. Rita is most comfortable. As can be seen (Figure 4), even when connecting all the manuals together, the pressing force increased slightly and was 1.6 N. Therefore, it is expedient to use a booster when joining the manuals together. The current development of technology gives organ builders many tools they can use when building new instruments.

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Project for construction of an oven for thermal processing of food

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Abstract: The tradition of baking in brick ovens dates back to 29,000 years BC. One of the oldest and operational oven is an oven dug up from the ashes and quite well preserved in Pompeii. The project involved preparation of documentation for the construction of the oven and its practical implementation. The main principles are: the internal diameter of the chamber is to be 110 cm, the height of the ceiling inside the combustion chamber is to be 40 cm, oven fired with wood and alternatively with natural gas. Analysis of wood and gas consumption needed to heat the oven to the right temperature. The characteristics of heating the oven chamber to operating temperature with the use of two types of fuel (wood and natural gas) and the characteristics of cooling the oven, which is important from the point of view of its operation, were also determined. The design of the oven was made both theoretically and practically. After completing all stages of construction, the oven fulfills its function of baking dishes at high temperatures.
Key words: design, construction, brick pizza oven, Pompeian oven.

1. Introduction

The tradition of baking in brick ovens dates back to 29,000 BC. They were used for mammoth cooking and often had a pit in the structure for baking and cooking.

One of the oldest and working ovens is one unearthed from the ashes and quite well preserved at Pompeii. It was built almost 2,000 years ago. It has remained functional to this day, although the last time it was used was in 79 AD – the day the volcanic eruption buried the city of Pompeii under a thick layer of ash. It was rediscovered after 17 centuries. The properties of the volcanic ash meant that all the architecture and the furnace were preserved in very good condition.

Nowadays, people are returning to the roots and traditions of cooking. With travel and easy access to information, more and more people are becoming conscious consumers and starting to pay attention to what they eat.

2. Project assumptions

The project assumes the execution of documentation for the construction of the oven. The main assumptions are:

- The inner diameter of the chamber is to be 110 cm;
- The height of the vault inside the combustion chamber is to be 40 cm;
- The height of the upper edge of the base of the furnace chamber is to be about 100 cm;
- The internal shape of the dome should be elliptical;
- Hybrid heating of the stove: by gas, or by wood;
- Chimney with a diameter of 180 mm.

3. Construction and principle of operation of the stove

The oven chamber rests on a traditional concrete slab reinforced with rebar.

The hearth of an oven should be at a height where you can easily make, place inside, and take-out food – usually about 100-110 cm. The height of the stove should be adjusted to the height of the person operating the stove.

The insulation layer – perlite concrete, or insulating concrete – rests directly on the concrete floor slab. The chamber insulation serves three purposes:

- a rigid surface separating the furnace chamber from the base used for, among other things, storing wood, or space for the gas burner;
- an insulating layer to prevent heat from escaping downward through the concrete slab;
- a smooth surface that will house the baking surface.

Pizza and bread are baked directly on the chamotte brick that forms the base of the oven's proper chamber, while other foods such as vegetables or meat are placed in baking trays.

The oven chamber is built in a spherical shape, with a lowered ceiling that forms an ellipse. The shape of the dome is designed to effectively absorb heat from a wood or gas fire, and to reflect the heat of the flame evenly onto the baking surface – where both the floor and food are heated. The bricks are bonded using a high-temperature mortar. The refractory bricks that make up the dome have the ability to retain heat, also will allow them to maintain and deliver the high temperatures needed to bake pizzas.

Unlike a traditional fireplace, in which the chimney is located inside the hearth at the back, the vent and chimney of the oven described here are located outside the oven chamber - at the front, above the oven opening. The vent as well as the chimney can be made of steel, brick or cast from a refractory mold.

The oven vent can be connected to: a modular double-wall steel chimney system, a single-wall steel chimney system, or a refractory flue pipe. The type of flue pipe used depends on whether the installation is outdoors or indoors, design choices and local building codes. A chimney cap, known as a canopy, should be installed at the top to minimize the penetration of precipitation into the chimney and stove, and to prevent sparks from escaping from the chimney.

After the stove dome and vent are installed, the stove is covered with insulation, usually a woven ceramic insulation blanket, known as a ceramic mat.

The finishing material of the stove must be primarily waterproof. The lower half of the stoves can be finished to match the upper half of the stove. Finishing materials usually include stucco, brick, stone, tile, marble, travertine and granite.

4. Stove design

The design of the construction of a hybrid wood and gas-fired stove shown in Figures 1-5.

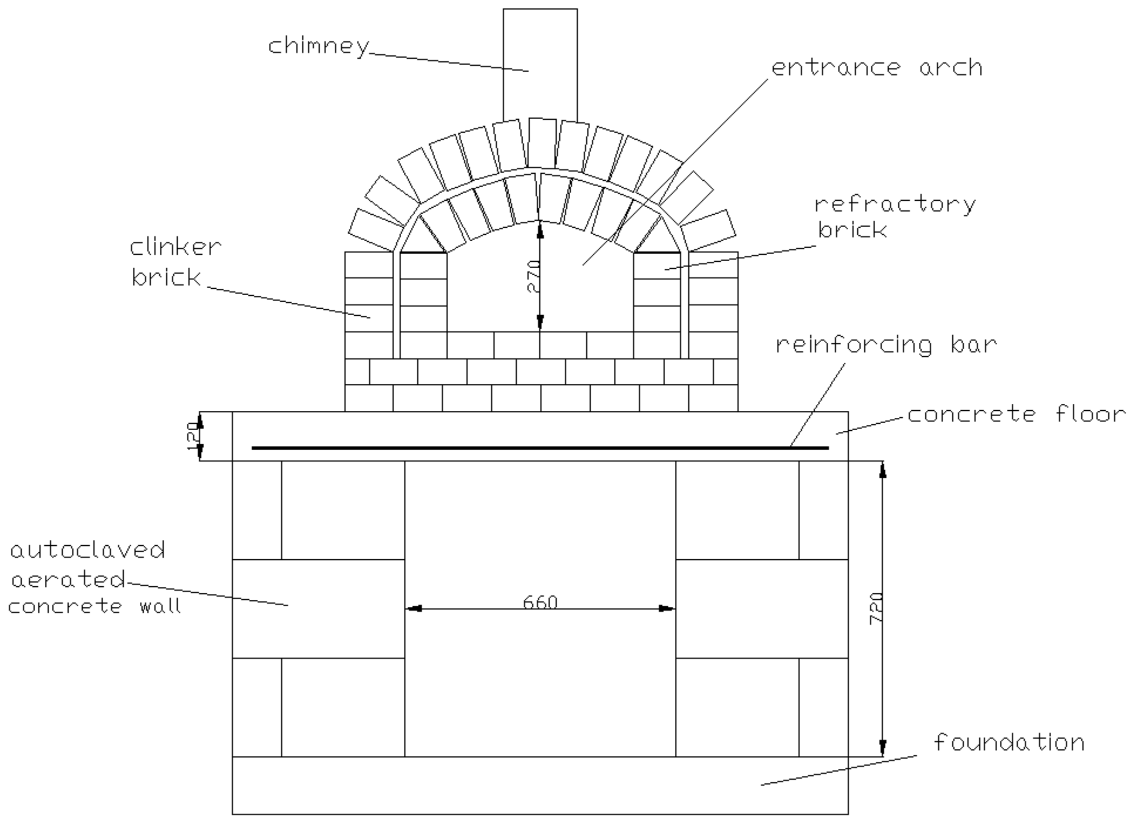

Figure 1. The front of the oven.
Source: own elaboration.

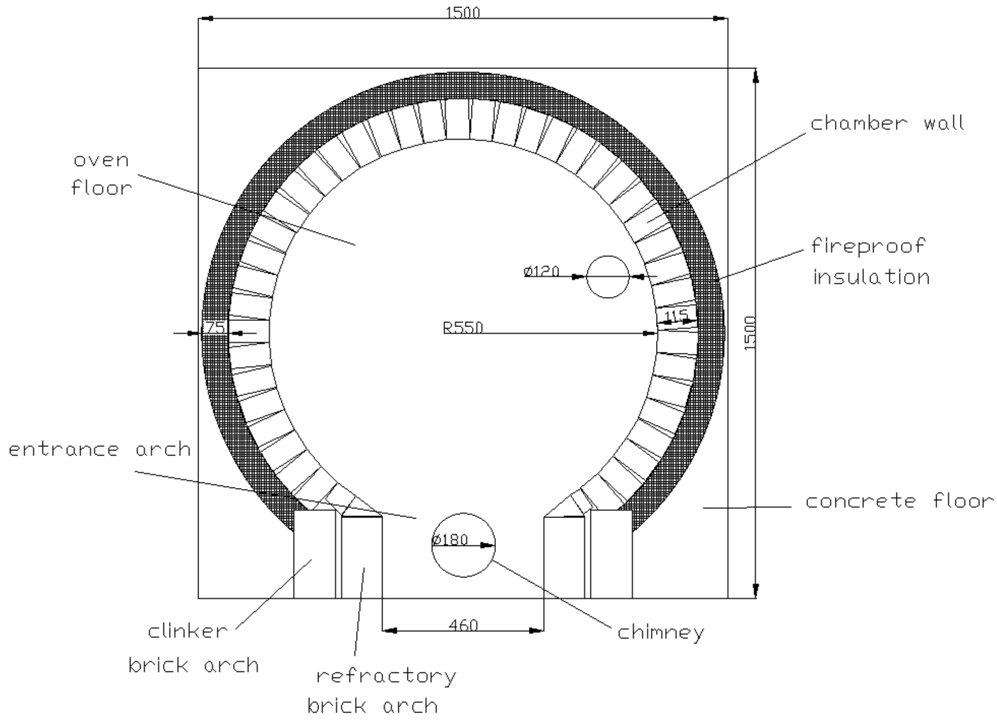

Figure 2. Top view of the oven.
Source: own elaboration.

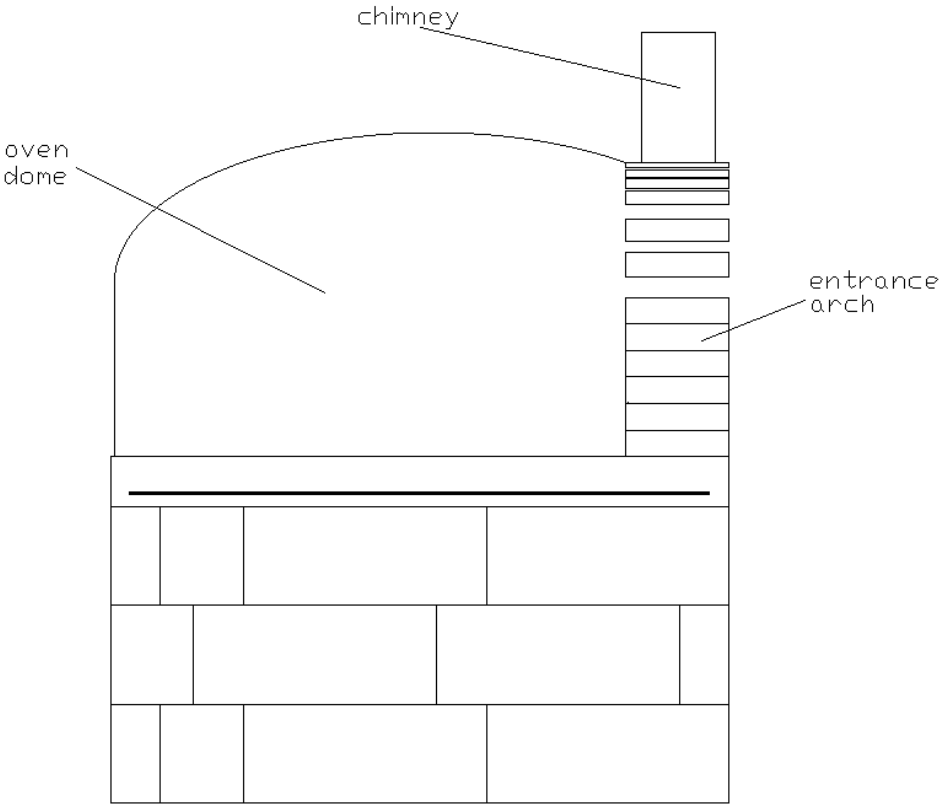

Figure 3. Side view of the oven.
Source: own elaboration.

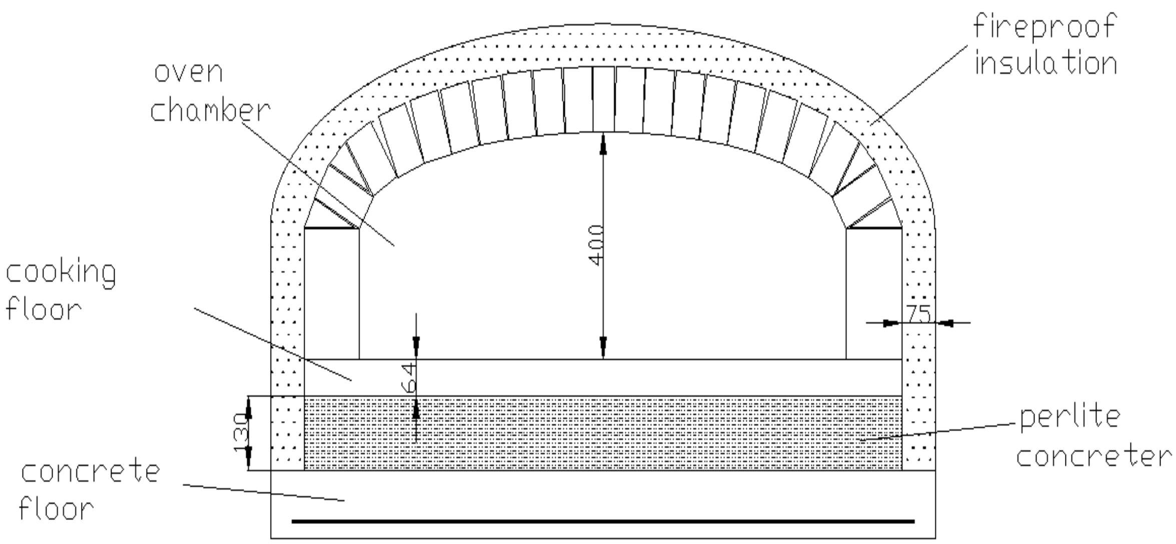

Figure 4. The shape of the oven chamber.
Source: own elaboration.

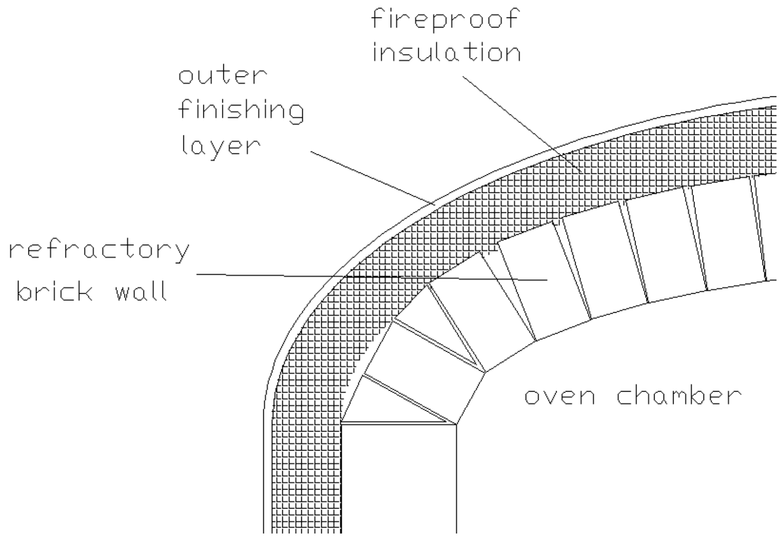

Figure 5. Cross-section of the oven wall.
Source: own elaboration.

5. Analysis of wood and gas consumption needed to heat up the oven to the correct temperature

Figure 6 shows the completed oven that is the object of the study.

Figure 6. Wood and gas fired hybrid oven.
Source: own elaboration.

There is no rule that says how much fuel to use and how long it will take to fire up to a specified temperature. This should be determined experimentally.

As material for heating the oven to the right temperature, you can use wood (hardwood or coniferous), gas (requires a special burner inside the chamber), or electricity (heaters placed in the walls and base of the oven).

Despite popular opinion, the species of wood burned does not significantly affect the taste and aroma of the baked food.

When laying the wood on the bottom, make sure that it does not adhere flat to its walls. In the middle you need to arrange a small pile, under which small branches are placed. They are set on fire, and after a while you should close the entrance hole with a sheet metal lid or door. The lid or door has an opening in its lower part through which air enters – this way you get proper circulation inside the oven chamber.

The generated chimney draught fuels the fire. At first, the wood burns only in the central part, but it quickly turns into embers, and the fire moves closer to the walls. The central part of the hearth remains free which allows oxygen to the back of the oven.

An interesting phenomenon will allow you to recognize that the oven has reached the right temperature: a moment after lighting in the oven, the walls of the chamber begin to be covered with soot, the layer of which becomes thicker and thicker over time. After about 20 minutes, you can see bright spots on top of the vault, which gradually increase their surface – this is a sign that the temperature of the walls reaches 5500.Then the ignition of soot occurs, which, burning out, exposes the chamotte bricks. After a while, almost the entire vault shines clean, and the remains of black tarnish are preserved only at the base. Do not add any more wood, only the embers at the bottom of the oven are left. The temperature of the walls slowly decreases, while the bottom continues to heat up. The further procedure depends on what you intend to bake in it.

The time it takes for the oven to heat up, the amount of fuel used, and the temperature it maintains, depends on the thermal capacity of the oven.

The thermal capacity of a brick oven can vary widely, depending on the thickness of the wall. The cradle oven described above has a dome with a total thickness of 22 cm and a hearth with a layer of 18 cm.

Too much thermal mass is very bad, as it takes a long time to heat such an oven and uses a lot of fuel. At the same time, too little thermal mass will be problematic. While an undersized oven shell may heat up quickly, it does not have the ability to retain heat to cook larger amounts of food, more pizzas or bread. When the fire stops the thinner oven will begin to give off heat as quickly as possible.

Table 1
Energy value of fuels

Fuel	Heat of combustion	Calorific value	Calorific value
Beech with 15% moisture content	20.1 [MJ/kg]	15.3 [MJ/kg]	4.2 [kWh/kg]
Natural gas	38.147 [MJ/m^3]	34.43 [MJ/m^3]	10.29 [kWh/m^3]

Source: own elaboration.

A study has been conducted to determine the heat capacity of the oven described above, and the necessary amount of fuel needed to heat it to the right temperature. The study assumes that the oven will be fired up to 500^{o}C using:

- Hardwood – beech;
- E-type high-methane natural gas.

In order to calculate the amount of heat required to heat the oven, you will need the formula:

$$Q = m \cdot c \cdot \Delta t$$

where:
Q – heat (energy flow) [J]
m – mass [kg]
c – is the specific heat [J/kgC]
Δt – temperature change [0^{o}C]

To calculate the weight of the oven, the following parameters were assumed:

- A standard chamotte brick weighs 3.3 [kg].
- 190 chamotte bricks were used to build the oven.
- A chamotte mortar with a total weight of 150 [kg] was used.
- The total weight of the oven is 777 [kg].

Then take the following calculation values:

- Weight of the oven – m = 777 [kg].
- Temperature rise – Δt= 4,800^{o}C (the oven temperature at the start is 200^{o}C).
- Specific heat of chamotte – c = 850 [J/kgC].

By substituting the values into the formula, the following data is obtained:

$$Q = 777\ [kg] \cdot 850\ \left[\frac{J}{kgC}\right] \cdot 480°C = 317{,}016{,}000\ [J] \approx 317[MJ]$$

In order to calculate the necessary amount of fuel to heat the oven chamber, we will need the values: heat of combustion and calorific value.

The heat of combustion is the amount of energy that is released during the combustion of a substance. If the product of combustion is water vapor, the heat of condensation also enters into the heat of combustion. Of course, it must be assumed that all the fuel is burned (complete combustion) and that the combustion is complete (i.e., there are no flammable substances in the flue gas).

When considering the heating value, you are dealing with the same amount of energy, but condensation of water vapor is not taken into account. Other conditions are unchanged.

Heat of combustion and calorific value are similar in definition, but different numerically. It is necessary to know what temperature the exhaust gas will be when it leaves the device. If below 100°C, then you can assume that the water vapor from the flue gas will condense in the device (as it is, for example, in condensing boilers) and the applicable quantity will be the heat of combustion. If this temperature is higher, use the calorific value. In the case of a particular oven, the flue gas temperature will be above 1000C, so the calorific value should be taken into account.

Knowing the calorific value of wood and natural gas, you can easily calculate the amount of fuel needed to heat the oven:

- Wood

$$317\ [MJ] : 15.3 \left[\frac{MJ}{kg}\right] = 20.7189\ [kg] \approx 20.7\ [kg]$$

- Natural gas

$$317\ [MJ] : 34.43 \left[\frac{MJ}{kg}\right] = 9.2070\ [m^3] \approx 9.21\ [m^3]$$

According to calculations, you should use about 20.7 kg of beech wood with 15% moisture content, or 9.21 m^3 of natural gas. In practice, however, it is a bit more, since the loss of heat escaping through the chimney and imperfect insulation must be taken into account.

Analysis of temperature rise and fall for wood and natural gas

Seasoned beech wood with a moisture content of 15% will be used to heat the oven, as well as a gas burner fueled by natural gas. The following measuring devices were used for the study:

- Benetech GM610 moisture meter;
- Medisana PS 414 scale;
- MeasureMe MT650C pyrometer;
- Intergas BK-G4M gas meter.

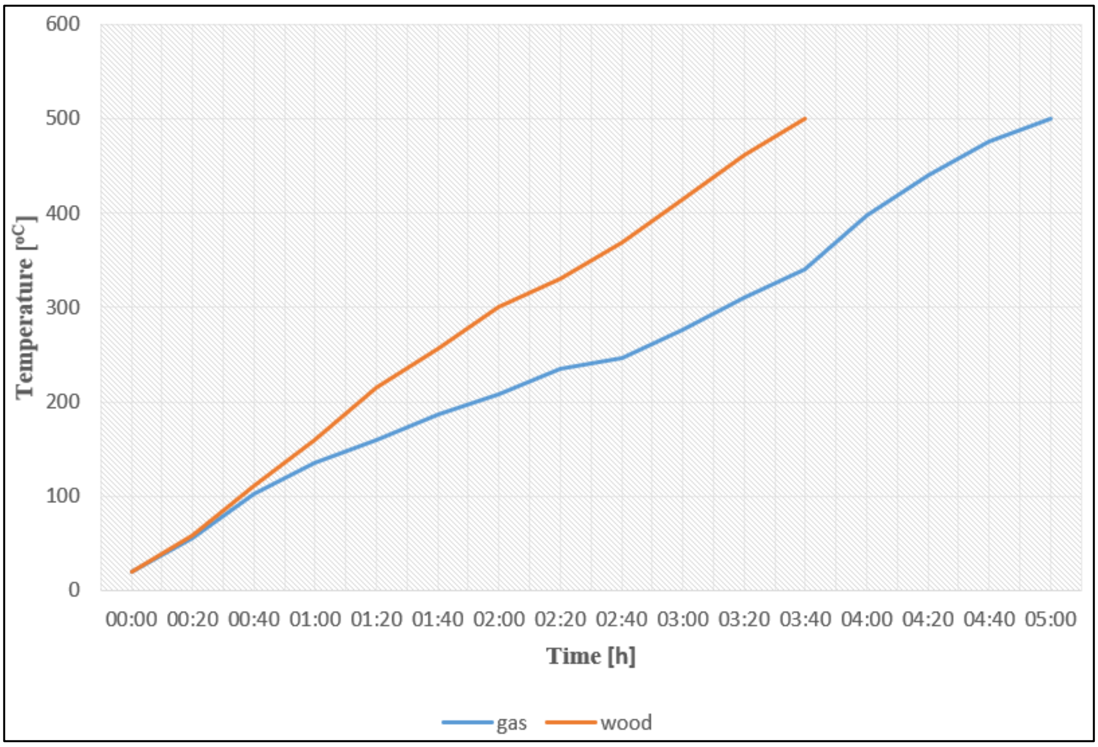

Figure 7. Oven temperature rise report.
Source: own elaboration.

Temperature measurements were taken at 20-minute intervals using the pyrometer. This is a very safe solution. This device allows you to measure high temperature in a non-contact manner, it works by measuring infrared radiation emitted by a heated object. Just press the trigger, point the laser pointer beam at the object to see its temperature on the display. The measurement was always taken in the same place: on a vertically placed brick, at a height of 10cm from the base of the oven.

According to the measurements, it appears that oven heating can be achieved faster with wood.

To heat the oven was used:

- 28.5 kg of wood,
- 11.83 m^3 of natural gas (according to the specifications of the burner should be 11.9 m^3).

The results of the study show that the amount of heat needed to heat the oven is greater than calculated in the earlier chapter. It is also easy to calculate the cost of heating the oven:

- The average price of a cubic (1 m^3) of beech wood as of 01/01/2023 is PLN 550. The weight of beechwood at 15% moisture content is 730 kg. Assuming that 28.5 kg of wood was consumed, its cost is 21.47zl.
- The price of 1 m^3 of gas as of 01.01.2023 is 2,66 PLN. To this price should be added subscription fees, transmission fees and additional charges, so the final cost is about 3 zl. Taking the approximate value of 3zl/1m^3 for the calculation, the cost of heating the oven was 34.89 zl.

Each time after heating with a given fuel, the oven was extinguished and the temperature drop was measured. The embers and ashes from the wood were taken out, and the gas burner, along with the gas supply, was cut off. The measurement took place every two hours, at the same point as when the temperature rise was measured.

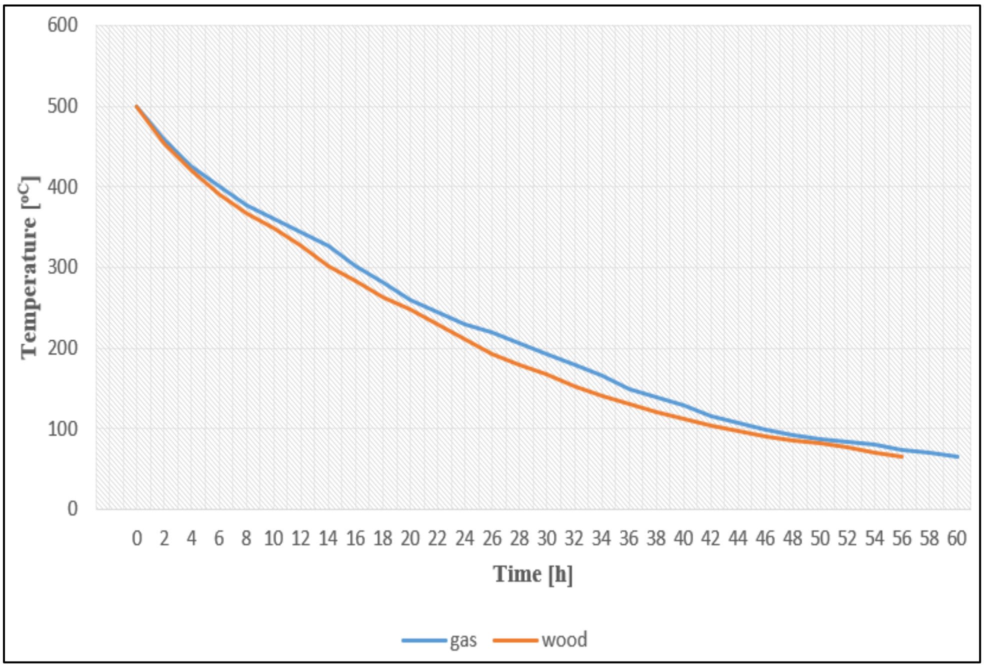

Figure 8. Oven temperature drop report.
Source: own elaboration.

6. Conclusions

The design of the oven has been carried out both theoretically and practically. After all the stages of construction, the oven fulfills its function of baking food at high temperatures. The oven reaches the temperatures established at the outset without problems. The oven's dimensions have been maintained, the chamotte brick does its job: it withstands high temperatures and holds and gives off heat for a long time.

From the tests carried out and after analyzing the results, it appears that the calculations made do not coincide with practice. The difference may be due to several reasons: heat loss escaping through the chimney, leaky oven insulation, inaccurate measuring devices.

It was also easy to calculate the cost of fuel required to heat up and reach the desired temperature. Heating with a burner may be more expensive, but you have to add to the cost of wood the time and labour involved in:

- unloading the wood,
- possible cutting into smaller pieces,
- stacking and storing large amounts of wood in a dry and airy place,
- cleaning the oven from the ash produced from burning the wood.

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Artificial intelligence in control processes using microcontrollers

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Abstract: The use of artificial neural networks and fuzzy logic implemented in microcontroller programs makes it possible to effectively realize nonlinear control processes. The only disadvantage of implementing artificial neural networks learned by the method of back propagation of error is the need to use external computers in the learning process. The set of inter-neural connection weights obtained in the process describing the entire control process can be implemented in the memory of the microcontroller without any obstacles.
Key words: artificial intelligence, microcontrollers, control.

1. Introduction

Most of the controllers being built are based on technology using microcontrollers. Microcontrollers, due to their design and increasingly rich equipment with a number of specialized input-output interfaces, are the best hardware platform for building controllers because they need very few external components to work. The memories used in them sufficiently allow the implementation of programs that use elements of artificial intelligence in the logic module.

2. Introduction to control systems

Controllers under construction often implement nonlinear control processes. Nonlinearities arise either from the e structure of the input signals or from the nonlinear course of the controlled process. This is a very significant difficulty in the implementation in relatively small microcontroller memories of complex algorithms implementing nonlinear processes.

The use of artificial intelligence elements makes it possible to simplify control algorithms for nonlinear processes. These elements are artificial neural networks and fuzzy logic. These two elements are characterized by the fact that the entire process of information processing is carried out numerically, which is an ease of implementation in the memory of the microcontroller. Expert systems, on the other hand, as they are based on processing information in explicit form in natural language, require relatively large information carriers for storing knowledge bases and rules. Processing information in natural language complicates the way communicating with sensors used to acquire information that is processed into signals that control actuators.

In neural networks, on the other hand, knowledge is contained in implicit form, in the form of a set of connection weights between layers of neurons. The process of learning a network is basically the process of implementing knowledge into the network structure with the simultaneous conversion of its form from the explicit form (learning examples) to the implicit form (weights assigned to specific connections of neurons with each other). In addition to the conversion of the form of knowledge in the learning process, there is also a process of knowledge compression. Thus, the size of the file containing the set of weights, which is basically a set of relevant knowledge in implicit form, is very small compared to the corresponding knowledge base of the expert system. This is ideal for simple systems implemented on the basis of 8-bit microcomputers. This fact can be confirmed by the results of research conducted by the author of the paper on the implementation of a neural network on a PIC 1657 microcontroller cooperating with a memory of small capacity (2 kB). Implemented on the above-mentioned microcontroller, the network forms a diagnostic system for the hydraulic pump of a combine harvester's power hydraulic system.

In the case of fuzzy logic, the process of converting input data into control signals proceeds in three phases: fuzzification (fuzzification), inference and sharpening (defuzzification). While the first and last stages do not present major difficulties in implementation using a high-level programming language, the inference process requires simple operations on strings that are linguistic variables as well as linguistic values, which is also not a programming problem.

3. Artificial neural networks

The most commonly used neural networks in technical applications are back-propagation error learning networks.

Having a set of weights of inter-neuron connections determined in the process of learning and testing the network, the response of the network to the forcing appearing at its input can be determined from the relationship:

$$O_j = F_2\left[\sum_{i=1}^{hid}\left(F_1\sum_{k=1}^{inp}(I_k \cdot W_{ik} + b_i)\cdot W_{ij} + b_j\right)\right]$$

where:

F_1, F_2 – activation functions of the hidden layer (sigmoidal) and the output layer (tagenshiperbolic),
AND k – value on the k-th input
ABOUT j – the value on the j-th output
IN ik – connection weights between the input layer and the hidden layer
b_i – the value of the offset (bias) of the hidden layer
IN ij – connection weights between the hidden layer and the output layer
b_j – output layer shift
hid – the number of neurons in the hidden layer
inp – the number of neurons in the input layer
j – the number of neurons in the output layer.

While the software implementation of the above relationship does not present major difficulties, the implementation of the activation functions for the hidden layer and the output layer can cause some problems. This is due to the limited numerical computation capability of the microcontroller on the one hand and a significant increase in the network response time when recalculating the values of these functions according to their original form. Therefore, the author has tested simplified versions of activation functions according to the relationship in many applications:

for a sigmoidal function

$$y = x \text{ for } -1 < x < 1$$
$$y = -1 \text{ for } x < -1$$
$$y = 1 \text{ for } x > 1$$

for the tangeshiperbolic function

$$y = 0.25x + 0.5 \text{ for } -2 < x < 2$$
$$y = 0 \text{ for } x < -2$$
$$y = 1 \text{ for } x > 2$$

The introduction of such simplification has fundamentally reduced the response time of the network as the rather complicated processing of the original form of the functional formulas has been avoided. However, the introduction of these simplifications resulted in an increase in the network processing error of 1% to 3%, which should not be a major problem as it is usually considered that the error of a properly trained network should not exceed 4% to 8% (Masters, 1996).

The disadvantage of such a solution is the need to learn and test the network on an external computer with much more computing power. After the completion of the learning and testing process, a set of weights of inter-neural connections and offsets (bias) can be implemented either in the microcontroller program itself or stored in the built-in EEPROM and at the time of microcontroller operation initiation is rewritten to microcontroller RAM where it will be visible to the program. This solution allows you to develop a universal program and each time you change the application, you change the set of weights and offsets in EEPROM without reprogramming the ROM.

4. Fuzzy logic

When implementing fuzzy logic in a microcontroller, three basic stages of data processing must be implemented. These are: blurring of the input data with the determination of the coefficient of data membership to the corresponding membership functions described by linguistic variables, inference based on a set of rules binding the linguistic variables of the input to the linguistic variables of the output, sharpening, i.e. transition from the qualitative domain described by the linguistic variables of the output to the quantitative domain which is the resultant value of fuzzy processing. The number of output linguistic variables must be consistent with the number of input linguistic variables. The paper presents a fuzzy logic model for the simplest model with one input and one output. The introduction of more inputs involves a significant increase in the number of rules determined by the product of the number of linguistic variables for each input, which significantly complicates the problem of implementing the fuzzy logic algorithm in the memory of the microcontroller. For example, for 3 inputs and 5 linguistic variables for each input, the number of rules will reach the number of 125 rules, which can significantly increase the response time of the system and may require a larger memory of the microcontroller program.

Thawing process (fusion)

The blurring process begins by determining the set of linguistic variables and the membership functions assigned to the linguistic variables. The most commonly used membership functions are the triangular, trapezoidal, L-class and γ class functions. The formal notation of these four functions can be presented as follows:

If $x > a$ and $x < b$ then $\mu = (x - a)/(b - a)$
Else
If $x > c$ and $x < d$ then $\mu = (d - x)/(d - c)$
Else
If $x \geq b$ and $x \leq c$ then $\mu = 1.0$
Else
$\mu = 0$

Listing 1. notation of the trapezoidal membership function, where:
a, b, c, d – breakpoints of the membership function (Figure 1)
μ – affiliation coefficient

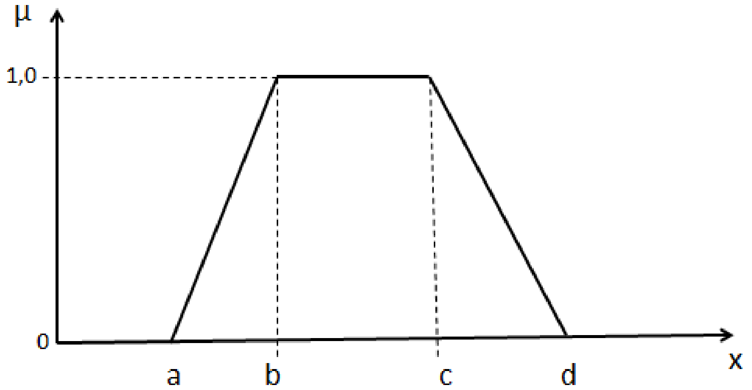

Figure 1. Trapezoidal membership function.
Source: own development.

Modifying Listing 1 accordingly, we can get a record of the other three membership functions:

when $b = c$, then we get the triangular membership function,
when we remove a but leave b, c, d, we get functions of class L,
when we remove d but leave a, b, c we get functions of class γ.

Rules

The inference process is carried out based on a set of rules that determine the links between input linguistic variables (LWE) and output linguistic variables (LWY). The syntax of the rule is as follows:

if LWE then LWY for 1 input and 1 output,
or
if LWEA and LWEB then LWY for 2 inputs and 1 output.

The number of rules is determined by the number of input linguistic variables and the number of inputs.

Often an array notation is used to write the rules, where input linguistic variables are assigned to output linguistic variables. Table 1 shows an example notation of four rules for four input and output linguistic variables.

Table 1
Rule notation for one input and one output

Rule No.	IF LWE is	THEN LWN
1	LWE1	LWY1
2	LWE2	LWY2
3	LWE3	LWY3
4	LWE4	LWY4

Source: own development.

However, in the case of two input linguistic variables and one output linguistic variable, the array notation can be presented as follows (Table 2).

Table 2
Rule notation for two inputs and one output 2

	LWEB1	LWEB2	LWEB3	LWEB4
LWEA1	LWY1	LWY1	LWY2	LWY2
LWEA2	LWY1	LWY2	LWY3	LWY3
LWEA3	LWY3	LWY3	LWY4	LWY4
LWEA4	LWY3	LWY4	LWY4	LEY4

Source: own development.

The process of sharpening (defasification)

The sharpening process boils down to determining the value of the output parameter according to the relationship (Nhivekar, Nirmale, Mudholker, 2011):

$$WY = \frac{\sum_{i=1}^{n}(P_i \cdot \mu_i)}{\sum_{i=1}^{n}\mu_i}$$

where:

WY – the output value after the sharpening process

μ_i – membership coefficient of the i-th linguistic variable

P_i – the output value of the peak of the membership function for which the membership coefficient $\mu_i \neq 0$.

The method used to calculate the output value is consistent with the method of sharpening the first maximum.

5. Conclusions

Solving a control problem using microcontroller technology is a complex issue from the programming side. While linear control can be described by a suitable algorithm, control when there are nonlinearities in the control process cannot always be described by even an elaborate algorithm. Microcontrollers, especially the commonly used 8-bit ones, have quite limited numerical computation capabilities. This makes it impossible to implement advanced control algorithms. The use of artificial intelligence elements largely solves this problem.

Fuzzy logic allows the implementation of simple controllers where there are one or two inputs and one output. The limitation of the number of inputs is due to the problem associated with the implementation of the inference module as it significantly increases the number of rules, which can cause delays in the response of the controller to changing forcing appearing on the inputs.

Artificial neural networks are suitable for implementing the control process where multiple inputs and multiple outputs are required. Information about the controlled object is contained in a set of interneuron connection weights in implicit and compressed form. The most commonly used are networks taught with a teacher by the method of backward error propagation. The learning process itself, due to the need to perform a lot of calculations, is carried out on an external computer, while the result of learning, that is, a specific set of interneuron connection weights and offsets, is implemented in the memory of the microcontroller.

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Production quality analysis by digital methods

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Abstract: A high level of steel door quality is essential in the battle for customers. In times of materialism and high consumption, when the product is generally available in a variety of editions, there is a need for the brand-manufacturer to stand out. A study was conducted that showed the role and importance of maintaining high quality of manufactured products. The following methods were used for the study: cause and effect analysis of defects FMEA, TQM management, 5S system, SIX SIGMA concept, LEAN MANAGEMENT system. The importance of quality control at various stages of production was proved: at the stage of structural design, at the stage of technological process design, at the, stage of production. A unique kind of importance of quality control obtains in large-scale manufacturing processes - serial or mass production, then considering the size of production and costs associated with quality control at the appropriate level. Methods called statistical are implemented, whereby on the basis of a random sample analysis allow reflections on the entire population. An important issue is how to select the sample, which must be characterized by reliability. Random sampling is carried out when: a full survey is too expensive, the effect of the survey is also to damage the door. One method to maintain the quality of the door is FMEA. Analysis of causes and effects of defects FMEA, is a method of identifying potential defects in a process or product, determining their possible causes, and identifying the risks that accompany a given defect. On the basis of this, a procedure is developed to minimize or eliminate the cause of defects. As a result of the company's continuous quality improvement, standards for the local, national or international market are introduced. Analysis of production quality by digital methods provided a compendium of information about the analyzed serial or mass production of steel doors.
Key words: metrology, defect identification, numerical methods, quality, geometric optimization.

1. Introduction

The quality of production is the main determinant of the direction of an entity's development against the industry. Digital methods make it possible to analyze production quality in a more precise and efficient than traditional methods. Through specialized measurement tools that have much higher measurement accuracy than conventional methods, it is possible to obtain an etalon-like product.

2. The importance of high-quality steel door manufacturing:

High quality steel doors are essential in the battle for customers. In times of materialism and high consumption when the product is generally available in a variety of editions there is a need for the brand to stand out from the competition. Quality measures to achieve a market advantage not only during a single purchase but also in the long term. Satisfied customer, if such a need arises in the future, will return for another product, because his needs have been satisfied. Also it may happen that as a result of his satisfaction he will recommend the product to another person who is currently looking for such an assortment. In this way the company makes another profit without much effort. This would not be possible if it were not for the high quality of the product obtained thanks to the tools that digitization gives us. A dissatisfied customer will not only not recommend the product further, but will also discourage potential customers from buying.

3. Research problem and research method

The research problem is the analysis of the quality of production of steel doors by digital methods, taking into account their targeted diversity and application at subsequent stages of construction production. The following methods were used for the study: cause and effect analysis of FMEA defects, TQM management, 5S system, SIX SIGMA concept, LEAN MANAGEMENT system.

Quality control, used in manufacturing processes, can be called checking, or measuring angles, diameters, lengths, and comparing the results with assumptions to determine whether compliance has been achieved for each of these characteristics (Brzezinski, 2013). Quality control takes various forms at different stages of steel door manufacture:

- At the design stage – checking understood as a determination of compliance, refers to the comparison of the obtained state with the designed state. Checking is done by designers and technologists.
- At the stage of designing the technological process – the control consists in assessing whether the adopted means of production and activities, give the opportunity to obtain the quality of the product in accordance with the design quality,
- At the stage of production – the control makes it possible to determine the compliance of the obtained quality of steel doors or their parts and components, with the requirements contained in the technological and construction documentation. With the help of a simulation program, the opening, length and width of the plating are checked.

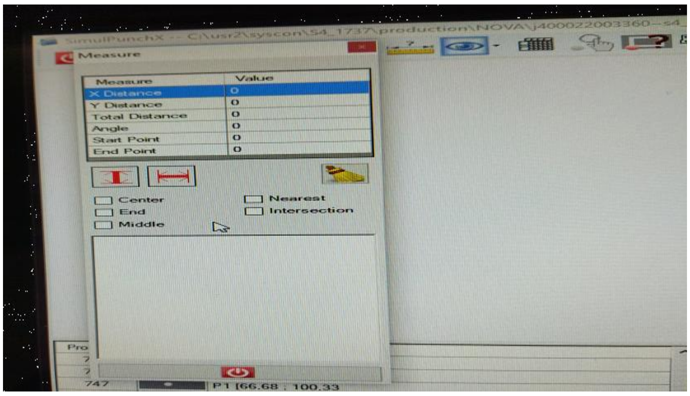

Figure 1. Measurement program.
Source: own elaboration.

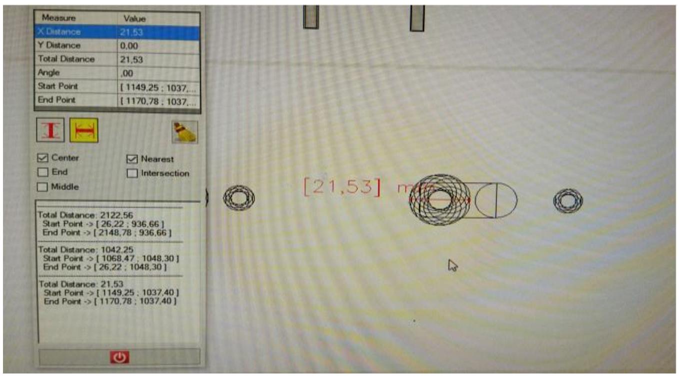

Figure 2. Measurement program-lock hole.
Source: own elaboration.

During the production of steel doors, very common quality defects occur at the production stage, most often due to direct inadequate contact with the material and human error.

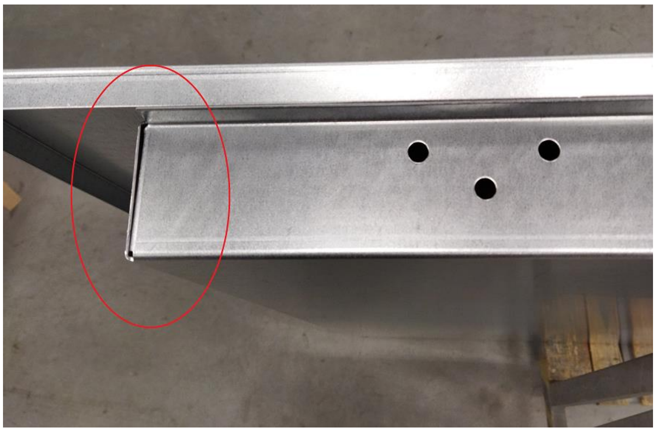

Figure 3. Badly dogged angle of inner plating.
Source: own elaboration.

A unique kind of importance of quality control obtains in large-scale manufacturing processes – serial or mass production, then, considering the size of production and the costs associated with quality control at an appropriate level, or rather, with the lack of inspection of all products, methods called statistical are implemented, through which on the basis of random sample analysis allow reflections on the entire population. This form of control is called sampling. The purpose of sampling is to obtain data on a particular batch by examining as few samples as possible. An important issue is how the sample is selected, which must be characterized by reliability (Lewkowska, 2010).

Sampling is carried out when:

- full study is too expensive;
- the result of the study is also the destruction of the door.

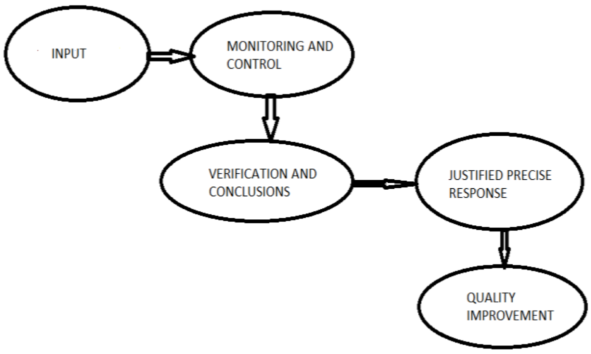

Figure 4. The idea of quality control with statistical tools.
Source: own elaboration.

One of the methods to maintain high quality doors is FMEA. Analysis of causes and effects of defects FMEA, is a method of identifying potential defects in a process or product, determining their possible causes, and identifying the risks that accompany a given defect. On the basis of this, a procedure is developed to minimize or eliminate the cause of defects.

Thanks to the FMEA method, it is possible to continuously improve the process by conducting further analyses, providing new ideas related to product and process improvement and effectively inactivating the sources of defects. The method can also be used during very complex processes, as well as in mass production and unit production (Szatkowski, 2014).

FMEA analysis is used in three situations (Szatkowski, 2014):

- designing a new product, process, steel door technology;
- modification of an existing process or steel door product;
- use of an existing product in a new environment.

Two types of FMEA analysis can be distinguished

FMEA analysis of the steel door project-to determine potential errors that may occur during the process of using the product and the resulting consequences.

FMEA analysis of the steel door manufacturing process – aimed at determining potential defects that may occur in the door manufacturing process.

Table 1

Sample FMEA sheet for steel doors

Type of defects	Reason for defects	Effects of defects	Current state				Corrective action	Improved state			
			LPW	LPZ	RFN	LPO		LPW	LPZ	RFN	LPO
Wrong angle of bend	Program error	undersides					Correction of the bending angle				

Source: own elaboration.

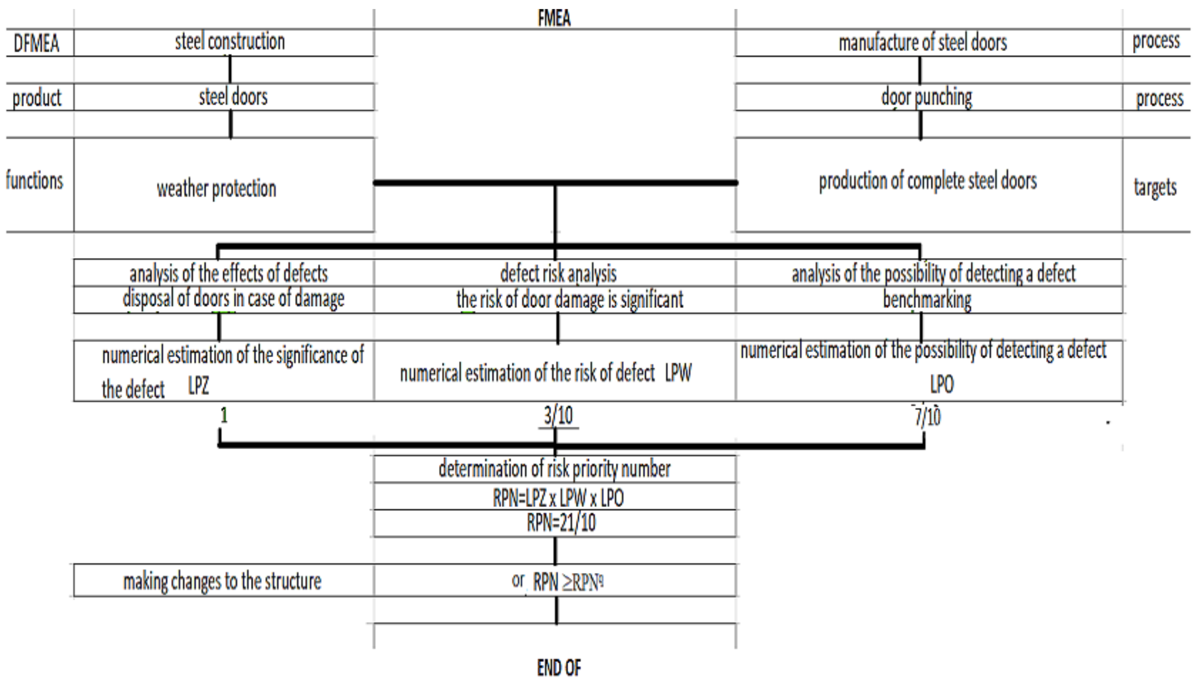

Figure 5. Algorithm of FMEA method of construction.
Source: own elaboration.

TQM – Management through quality- an approach to door production management, in which quality comes first and everything is subordinated to it. It involves all employees of the plant. The goal is to achieve long-term success with the aim of satisfying the customer and gaining benefits for the door manufacturing company, its employees and the public using the manufactured steel doors in their daily lives (Pasternak, 2015).

When producing steel doors at each stage of their creation, there are situations in which there are opportunities for waste of material, energy and time. To minimize such a situation, the LEAN MANAGEMENT system is used, thanks to which waste is minimized without affecting the value of steel doors. It pays attention to small aspects in the production plant that have a huge impact on the final result.

During the preparation of door sheathing, the selection of the smallest possible sheet significantly affects the amount of unnecessary production waste, but it must be remembered that it can not be less than the development of the length and width of the steel door leaf.

The implementation of the 5S system, which is a set of activities and procedures through which it is possible to establish, implement and maintain quality production, certainly improves the entire process of steel door production. By assigning specific storage locations to tools and equipment, it increases work safety and allows job rotation of employees, which eliminates monotony. Assigning storage places for production waste increases work efficiency because the employee does not look for a place where to throw the waste, but reflexively, gets rid of it without wasting time on unnecessary dilemmas. Regular audits, i.e. inspections aimed at improving the work at individual workstations, directly influence the development of workstations where steel doors are produced and improve the entire process by directly controlling high quality. This is manifested in the SIX SIGMA concept.

As a result of the company's continuous quality improvement, there is the introduction of standards applicable to the local, national or international market. A standard is a document adopted as a result of findings and approved by the relevant organizational unit. It contains rules, characteristics, guidelines relating to steel doors.

Thanks to the standard, it is possible to control the quality of production, through a uniform system applicable to each employee.

Standards taking into account the production of steel doors:

- PN-EN 14351-1+A1:2010 Windows and doors. Product standard.
- PN-EN 1192:2001 Mechanical strength.
- PN-EN 12400:2002 Resistance to repeated opening and closing.
- PN-EN ISO 10140-2 (2011) Sound insulation.
- PN-EN ISO 10077-1:2007 heat transfer coefficient.

4. Results

The analysis of production quality by the digital methods mentioned above provided a compendium of information about the analyzed serial or mass production of steel doors. The comprehensive metrological evaluation was within the ranges imposed by the designers. Thanks to the methods used, the designs had optimal manufacturing accuracy, which could not be achieved in the previous analysis system. Thanks to a number of methods, it is possible to detect a manufacturing defect early and eliminate it at the earliest possible stage, which will undoubtedly benefit the operation of the company and reduce the cost of further production made on the defective product and avoid the costs associated with the disposal of doors. Inspection at early pre-production stages also eliminates duplication of a detected programming error, which in the long run will pay off in profit as a result of greater savings in time, material and energy.

5. Conclusions

When analyzing the quality of production by digital methods, it should be said that it plays a very important role at all stages. Based on the evaluation of complete data from the manufacturing process, it is possible to predict quality risks.

Lack of proper control at the production stage can result in unwanted defect.

In an era of materialism and consumption when the product is available in various editions and from various manufacturers. In order to stay in the market, a manufacturer must distinguish itself through a top-quality product, and such is made possible by digital methods because of the type of action taken and the precision of detection of the problem, which enables an accurate and effective response.

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PN EN ISO standards:

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Analysis of efficiency in the use of machinery – a case study

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Abstract: The base of a properly and efficiently operating enterprise is, among other things, an orderly and systematized production system. An important element of any production process is machinery, whose main task is to maintain production capacity at a high and constant level, which in turn ensures the continuity of production. One of the concepts of total and team maintenance of machinery and equipment at all levels of the organization, is the Total Productive Maintenance (TPM) method. The goal of this method is to use machinery as efficiently as possible, thereby eliminating waste generated by failure and also to achieve a level of zero starts and failures. The scope of the study was to analyze the efficiency of machine utilization by means of selected operating indicators.

The analysis shows that the average values of the OEE index for the studied machines are high and amount to 80-87%. The values of Mean Time Between Failures (MTBF) are quite diverse. Most of the recorded failures were the result of aging machines and exploitation of their components. On the other hand, the Mean Time to Repair (MTTR) indicator remains at a low (satisfactory) level. Based on the analysis, it can be concluded that effective machinery fleet management methods have been implemented at the plant. The collected results provide a starting point for prioritizing and taking improvement measures to increase the efficiency of the machinery, which obtained the lowest value of this indicator. The analyzed indicators relate not only to the machinery park, but also allow us to assess the organization of the Maintenance Department, production processes, and management of material resources.
Key words: Overall Equipment Effectiveness, OEE, MTTR.

1. Introduction

The basis of a properly and efficiently operating enterprise is, among other things, an orderly and systematized production system (Hamrol, 2015). An important component of any production process is machinery, the main task of which is to maintain production capacity at a high and constant level, which in turn ensures the continuity of production.

One of the concepts of holistic and team-based maintenance of machinery and equipment at all levels of an organization, is the Total Productive Maintenance (TPM) method. At the core of TPM is the prevention of any failures through periodic maintenance, planned repairs and continuous prevention.

TPM system identifies 6 major takeoffs that cause productivity disruptions and (Nowicki, 2019):

- equipment failures;
- takeoffs related to changeover, adjustment, calibration;
- Idleness and micro-stops;
- organically the speed of the machine;
- defects and corrections;
- startups related.

The goal of TPM is to use machinery as efficiently as possible, thus eliminating waste generated by failure and achieving zero start-ups and failures. To achieve these goals, the tool Autonomous Maintenance is used. It is a set of tasks designed to involve operators in the maintenance and upkeep of machines that are operated by nothing. These activities include (Hyla, 2019):

- daily reviews;
- oiling, lubricating;
- cleaning;
- parts replacement;
- abnormality detection;
- simple repairs;
- inspection and calibration.

The implementation of TPM should contribute to the switch from a reactive approach to a predictive function. TPM is supposed to change the realization that proper operation does not depend only on maintenance services, but on all employees at each level. Ultimately, TPM leads to safe, efficient and trouble-free operation. As a result, the goals and strategies of the entire organization can be realized, resulting in profits for all employees of the company (Blaczkowska, 2019).

By using this method, an increase in productivity and greater availability of the machinery fleet can be achieved (Dillon, 2017). However, the implementation of specific methods of supervising the operation of machinery and technological equipment in the enterprise requires periodic evaluation of the effectiveness of the implemented activities and the state of the technical infrastructure in place. The basis for this is the selection of appropriate evaluation metrics. These metrics are used to evaluate the activities undertaken in the maintenance of machinery and indicate their performance in conjunction with the established goals of the organization (Antosz, Stadnicka, 2015). A number of indicators for evaluating the work and supervision of machinery are defined in the literature, including the key indicator of machine utilization efficiency OEE, or the average time between repairs MTTR (Gulati, Smith, 2009; Kornicki, 2009; Ljungberg, 1998).

The publication undertakes to analyze the efficiency of machine utilization in a selected company using the above indicators.

2. Purpose and scope of the study and descriptions of research methods

The scope of the research was to analyze the efficiency of the use of selected machinery by means of operational indicators in terms of the effectiveness of the Maintenance Department.

The analysis was made on the basis of: maintenance service records, observations and interviews with employees at various levels, starting with mechanics, electricians, automation technicians, through department masters, the UR master, and ending with production department managers and the UR department manager. Information was collected on the supervision of machinery, how failures are reported, recorded and rectified, the types of downtime recorded, how scheduled work is carried out, including inspection and maintenance and overhaul.

The first stage was to analyze the performance of the Maintenance Services of the selected organization. The next stage was the selection of a group of machines. Further, the maintenance programs of the selected machines and repair, maintenance plans were reviewed. An analysis was made of strategies for removing failures and methods to support the operation of the services.

The next stage of the study was to collect and analyze data on damage, downtime, repair times, maintenance, overhaul. An analysis of the causes of failures was also carried out. In the next step, key performance indicators for machine utilization were determined, including: MTTR, MTFB and the total efficiency index of individual machines (OEE technical). Production loads of selected machines were studied over a 1-year period.

3. Analysis of machine efficiency

3.1. Machinery damage analysis

The study of the work began with a review of the machinery park. The analyzed organization has production halls, which are equipped with machines located in the machining and tooling departments. The machinery park consists of 56 machines. These include both conventional lathes and milling machines, conventional grinding machines and CNC machines: lathes, milling machines and band saws. Due to such a large number of machines, the machines selected for analysis were those that qualified as critical machines in the production processes (they were marked with symbols M1 to M11):

- CNC column milling machine (M1);
- CNC 3-axis milling machine (M2);
- vertical band saw (M3);
- 5-axis machining center (M4);
- vertical machining center- 3-axis milling machine (M5);
- vertical machining center- 3-axis milling machine (M6);
- CNC automatic lathe- (M7);
- conventional lathe (M8);
- CNC turning center- (M9);
- CNC lathe center- (M10);
- CNC- (M11) turning center.

As part of the study, data on failures during the study period was analyzed. A total of 91 failures occurred during the year. The occurrence of these malfunctions was classified as those that take a particular machine out of service. Figure 1 shows the number of hours of downtime for each machine resulting from failures during the study period.

An analysis of the collected data shows that the M6 machine did not suffer any malfunctions in the year under review – it is a new machining center. The CNC turning center (M9) is also a relatively new machine; the only failure that occurred on this machine was damage to the guard (a dent resulting from a piece of workpiece material placed in the machining jaws breaking off). In contrast, the CNC automatic lathe machine (machine M4) showed the highest failure rate. The main failure here was damage to the air conditioner.

The next figure (Figure 2) shows the classification of failures by area of occurrence. As can be seen (Figure 2), the highest failure rate of machines is associated with the mechanical area. This is due to the fact that the machines are heavily used and operate in harsh working conditions (dust, temperature).

Analyzing the reported failures, it can be concluded that the resulting failures are most often the result of wear and tear, aging of individual machine components, operating conditions of the machine in question, mechanical factors. Wear and tear of machine parts, mechanisms is an inherent process associated with the operation of the machine. The result of this process is the loss of working capacity.

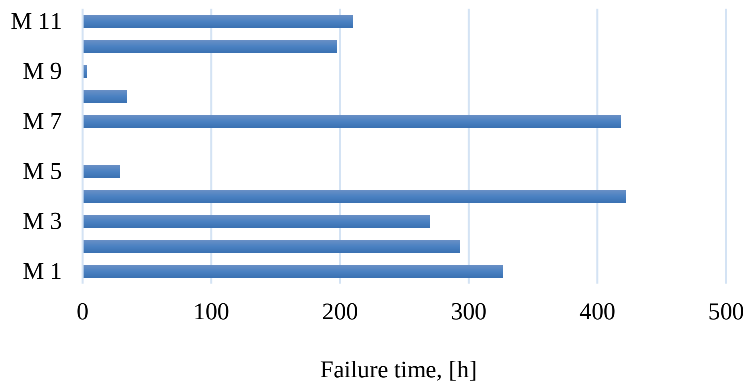

Figure 1. Total downtime due to individual machine failures.
Source: *Analiza utrzymania ruchu w wybranej firmie produkcyjnej*, M. Petryszak, 2020, praca dyplomowa na kierunku Zarządzanie i inżynieria produkcji, Nowy Sącz: Instytut Techniczny PWSZ w Nowym Sączu.

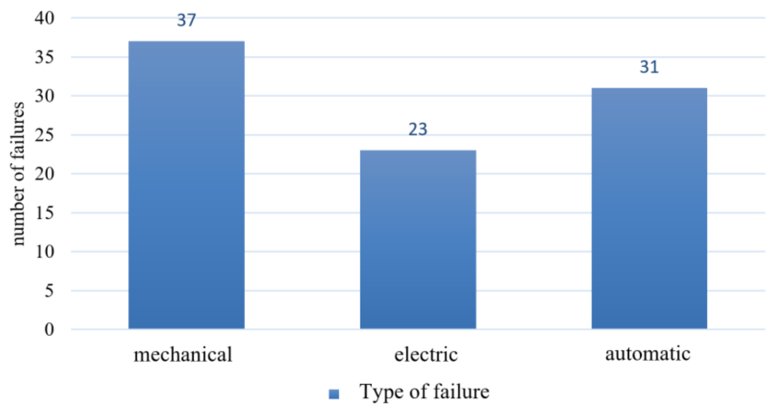

Figure 2. Breakdown of failures by area of occurrence.
Source: *Analiza utrzymania ruchu w wybranej firmie produkcyjnej*, M. Petryszak, 2020, praca dyplomowa na kierunku Zarządzanie i inżynieria produkcji, Nowy Sącz: Instytut Techniczny PWSZ w Nowym Sączu.

Many failures could have been prevented, thanks to the machine management system (TPM) implemented at the company and the preventive maintenance performed. It is then possible, at the inspection stage, to catch symptoms that could signal an impending failure and prevent damage without unnecessary downtime. A total of 607 periodic inspections of machinery were performed in the year under review: 158 electrical inspections, 379 mechanical inspections and 70 automation inspections. Table 1 summarizes the number of machine inspections performed, taking into account their periodicity and type.

The analysis also shows that a total of 13 overhauls were carried out during the study period, covering 6 of the 11 machines examined. A list of the performed overhauls along with their duration is summarized in Table 2.

Table 1
Maintenance of machines in the year under review

Reviews:	***electrically***				***mechanically***					***in the field of automation***	
Machine	monthly	quarterly	six months	annual	weekly	monthly	quarterly	six months	annual	monthly	six months
M1	12			1		12		2	1		
M2	12	4		1	53		4	2	1	12	2
M3	12			1		12			1		
M4	12	4		1	53	12	4	2	1	12	2
M5	12		2	1	53	12	4	2	1	12	2
M6	12		2	1	53	12	4	2	1	12	2
M7	12			1		12	4	2		12	2
M8	12		2	1		12		2	1		
M9	12					12					
M10	12		2	1		12		2	1		
M11	12			1		12		2	1		

Source: *Analiza utrzymania ruchu w wybranej firmie produkcyjnej*, M. Petryszak, 2020, praca dyplomowa na kierunku Zarządzanie i inżynieria produkcji, Nowy Sącz: Instytut Techniczny PWSZ w Nowym Sączu.

Table 2
List of renovations carried out in the year under review

Machine	**Renovation**	**Duration, h**
M1	Overhaul of milling machine angle head	88
M3	Replacement of 1800 saw wheel bandages	91
M3	Replacement of table plates and saw guide screws	43
M4	Replacement of X axis bolt bearings	18
M4	Reconditioning of the X axis ball screw	37
M5	CNC milling machine vibration on axis screw	122
M5	Replacement of the Y-axis bolt – DMF 180	146
M5	Overhaul/repair of angle head	18
M5	X axis bolt replacement KPL. Design change	28
M6	Checking table geometry, adjusting	141
M7	No possibility of milling	71
M7	No TC-116 milling capability	27

Source: *Analiza utrzymania ruchu w wybranej firmie produkcyjnej*, M. Petryszak, 2020, praca dyplomowa na kierunku Zarządzanie i inżynieria produkcji, Nowy Sącz: Instytut Techniczny PWSZ w Nowym Sączu.

All the renovations carried out were in the mechanical area. It can be seen that carrying out overhauls is very time-consuming, and machines were out of service during this period. Therefore, it is very important to properly prepare a plan to carry out the overhaul and secure adequate resources and manpower to keep the overhaul time as short as possible. In most cases, overhaul work was the result of machine inspections (e.g., "replacement of wheel bandages" on machine M3) and based on operator reports ("overhaul of angle head" on machine M1). Overhaul can also be the result of reports of irregularities detected by the quality control cell, whose task is, among other things, to observe measurement trends (overhaul "regeneration of X axis ball screw" on machine M4 or "CNC milling machine vibration on axis screw" of machine M5. If the parameters of finished products begin to deteriorate (but are still within the established tolerance), the employee informs the decision-makers. Some of the overhauls were the result of design changes made. It is worth noting that the planning of time-consuming overhauls takes into account periods of production downtime in the department (such as holiday breaks).

3.2. Machine utilization efficiency indicators

In the next step of the conducted analysis, selected operational indicators of the studied machines were determined. Monitoring the reliability of the technological park is one of the challenges that maintenance managers face on a daily basis. Proper management of failures can help significantly reduce their negative impact on the production process. To help effectively manage failures, a group of critical indicators have been designated that should be monitored, i.e. OEE, MTTR, MTBF. By tracking these key indicators, an organization can maximize uptime and keep disruptions to a minimum.

The OEE indicator can be used at three levels: plant (global), production line and machine process (technical).

This parameter is calculated, as the product of three components: availability, utilization (efficiency), quality (1):

$$OEE = D \cdot W \cdot J \tag{1}$$

where:

D – availability, %
W – utilization, %
J – quality, %.

The accessibility index is calculated according to relation (2):

$$D = \frac{t_d - t_p}{t_d} \cdot 100\% \tag{2}$$

where:

t_d – time available, h
t_p – downtime, h.

The utilization rate is calculated from relation (3):

$$W = \frac{l + l_w}{t_d \cdot w} \cdot 100\% \tag{3}$$

where:

l – number of units produced, pcs
l_w – number of defective pieces, pcs
t_d – time available, h
w – shift capacity, *pcs·h-1*.

The quality index is calculated according to relation (4):

$$J = \frac{l - l_w}{l} \cdot 100\% \quad (4)$$

where:

l_w – number of defective pieces, pcs
l – number of units produced, pcs.

Figure 3 summarizes the calculated values of each machine's OEE (technical) performance index with its components: Availability (D), Productivity (W) and Quality (J) by month.

Analyzing the above indicators, it can be concluded that any downtime, breakdowns, repairs negatively affect the availability parameter (D), and this translates into a decrease in the overall efficiency of machine utilization. The values of the OEE indicator with a near-sinusoidal (Figure 3: M7) or sawtooth (Figure 3: M11) waveform indicate that the operation of these machines is highly unstable. Therefore, it is necessary to analyze the causes of these events and strive to eliminate errors and irregularities.

In the month of December, all machines show a decrease in OEE. This is due to the fact that this is the period where a large number of both monthly and annual maintenance is performed. This affects the decline in the D component, or availability. This month also has the lowest number of working days, which also affects the result of the above indicator.

It is worth noting that the J-index, or quality, has reached 100% in certain months. This is achievable because the plant's goal is to minimize shortages.

Considering the average values of OEE indicators (Table 3), it should be noted that only three machines (M6, M8 and M9) achieved the expected OEE value of 85%.

Table 3
Average OEE values for each machine

Machine	M 1	M 2	M 3	M 4	M 5	M 6	M 7	M 8	M 9	M 10	M 11
Average annual OEE	81.88%	80.65%	82.78%	79.93%	82.73%	86.02%	56.62%	87.06%	88.88%	81.91%	81.77%

Source: *Analiza utrzymania ruchu w wybranej firmie produkcyjnej*, M. Petryszak, 2020, praca dyplomowa na kierunku Zarządzanie i inżynieria produkcji, Nowy Sącz: Instytut Techniczny PWSZ w Nowym Sączu.

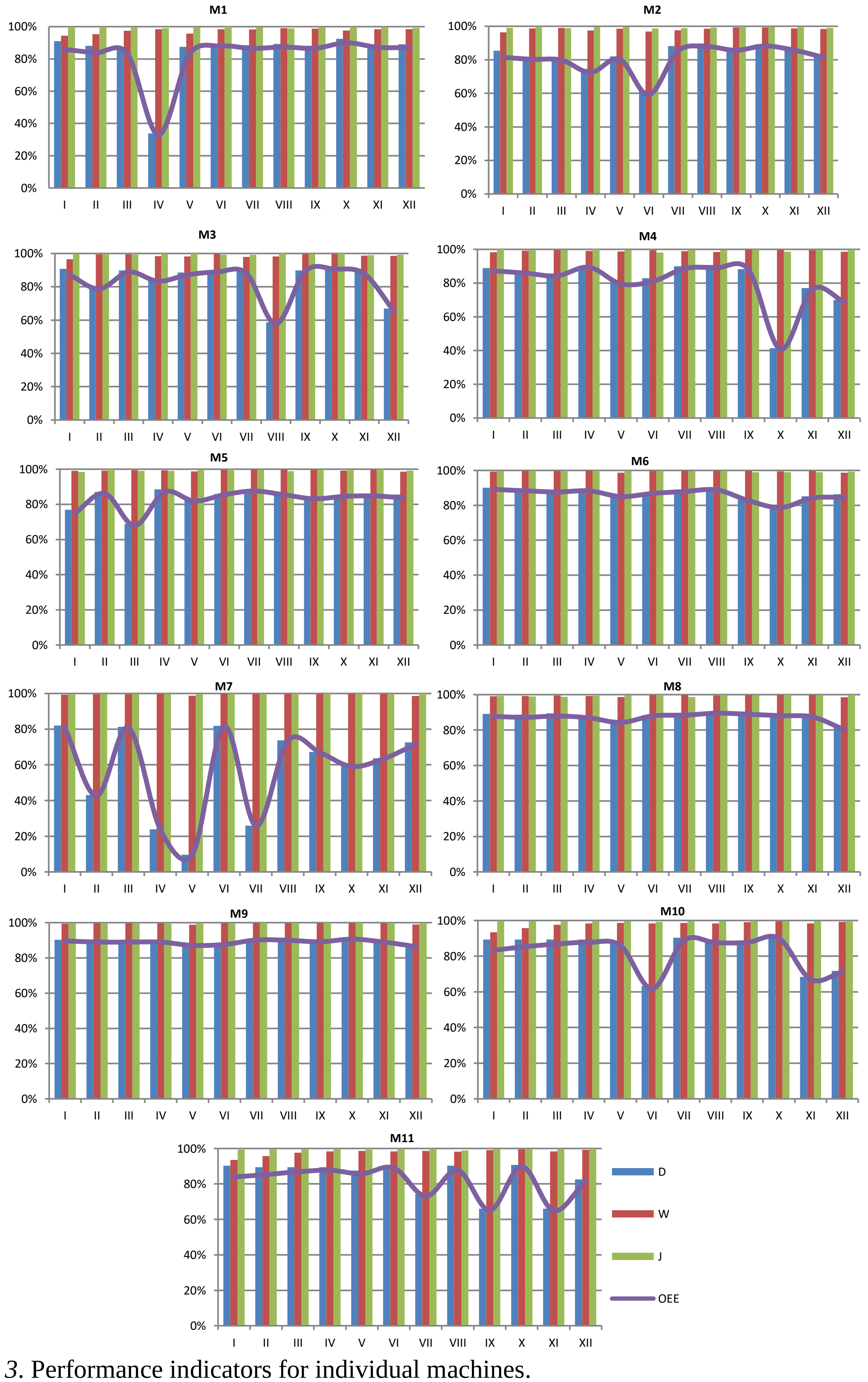

Figure 3. Performance indicators for individual machines.
Source: *Analiza utrzymania ruchu w wybranej firmie produkcyjnej*, M. Petryszak, 2020, praca dyplomowa na kierunku Zarządzanie i inżynieria produkcji, Nowy Sącz: Instytut Techniczny PWSZ w Nowym Sączu.

The collected results provide a starting point for prioritizing and taking improvement measures to increase the efficiency of the machines that obtained the lowest value of this indicator.

In the last step of the analysis, indicators were determined: mean time to repair (MTTR) and mean time between failures (MTBF).

The MTTR (Mean Time To Repair) indicator indicates the average repair time. It quantifies the amount of time it takes to repair a machine and restore it to full functionality. It covers the period when the repair begins and continues until operation is restored. This is the repair time, the test period and the return to normal operating condition.

The MMTR index is calculated according to the relationship (5):

$$MTTR = \frac{t_A}{n_p} \tag{5}$$

where:

t_A – repair time

n_p – number of repair incidents.

MTBF (Mean Time Between Failure) is the average time between failures. MTBF measures the expected time between one previous mechanical/electrical system failure and another failure during normal operation.

The determined values of MTTR and MTBF for each machine are summarized in Figure 4.

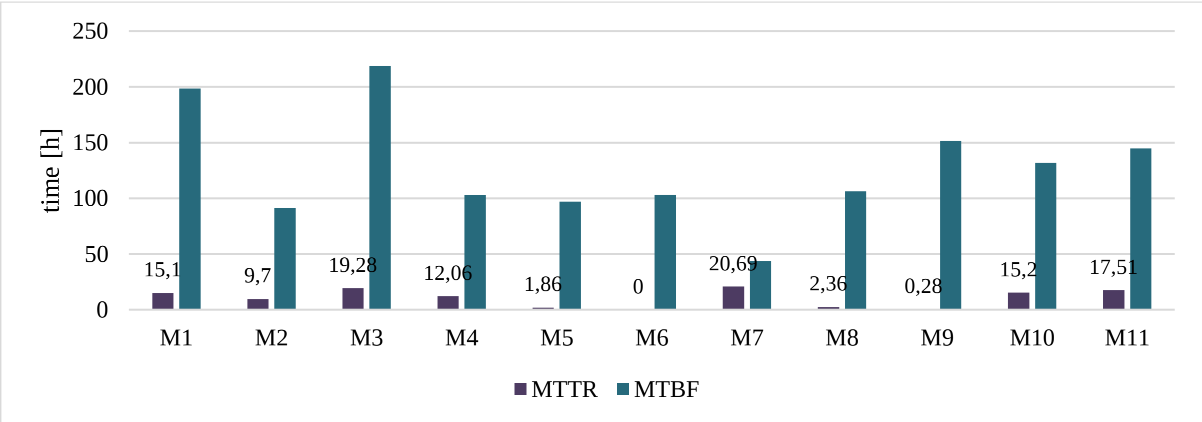

Figure 4. MTTR and MTBF values of individual machines.

Source: *Analiza utrzymania ruchu w wybranej firmie produkcyjnej*, M. Petryszak, 2020, praca dyplomowa na kierunku Zarządzanie i inżynieria produkcji, Nowy Sącz: Instytut Techniczny PWSZ w Nowym Sączu.

Analyzing the chart above, it should be noted that the MTTR rate remains low. The time spent on removing failures and restoring the machine to operation is less than 5% of the available time. This means that the Maintenance Service is taking quick action to restore the machines to full operation.

In contrast, the M7 machine shows the lowest MTBF values. The higher the MTBF value, the longer the machine is likely to operate properly before failure.

For critical facilities, MTBF is an important indicator of expected performance. Although MTBF does not take into account scheduled maintenance, it can be applied to issues such as calculating maintenance intervals for preventive replacements. If it is known that a machine is likely to operate for a certain number of hours before failing again, introducing preventive measures such as lubrication or recalibration can help minimize this failure and extend the equipment's uptime To improve MTBF performance, consideration should be given to reducing the number of overhauls.

4. Conclusions

The monitored indicators are key in improving processes related to Total Machine Maintenance (TPM). Based on the analysis, it can be concluded that effective machinery fleet management methods have been implemented at the plant.

An in-depth knowledge of OEE provides an understanding of how machine processes can be made more efficient, often without incurring huge investment costs. Monitoring and improving the indicators, leads to increased machine availability, improved quality of finished products, extended uptime cycles, increased efficiency of technical resources.

It should be emphasized that most of the recorded machine failures were not caused by improperly or carelessly performed work by Maintenance specialists, but were the result of aging machines and exploited components.

However, it is proposed, on the most failing machines, or machines subjected to continuous operation (M2, M3, M4, M7), to introduce automatic observation of the production cycle. The advantage of such a solution is the ability to directly collect data on micro-downtimes or productivity declines of a still-running machine. This will contribute to the reduction of machine downtime associated with the occurrence of failures.

The analyzed indicators relate not only to the machinery park, but also allow to assess the organization of the Maintenance department, production processes, and management of material resources. It is also important to ensure effective cooperation and understanding between the management of UR Services, the management of production departments and operators during the introduction of changes related to the implementation of operational indicators.

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Application of text mining methods in the context of production management systems

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Abstract: Text mining is the process of exploring and analyzing large amounts of unstructured text data aided by software that can identify concepts, patterns, topics, keywords, and other data attributes. Text mining and analysis helps organizations find potentially valuable business information in company documents, customer emails, call center logs, literal survey comments, social network posts, medical records, and other textual data sources. Machine-to-machine and machine-to-human communication is a key element of Industry 4.0. To make data-driven decisions and reduce our reliance on human labor, factories and industrial processes need rich integration between the hardware and software involved in manufacturing. Interactive document exploration allows you to find previously unknown patterns in document collections and apply them directly to predictive models, present them as part of a corporate taxonomy or corporate dashboards – maximizing the value of acquired knowledge from all sources of information related to production processes.
Key words: text mining, NLP, Industry 4.0, Spark NLP.

1. Introduction

Text mining is the process of exploring and analyzing large amounts of unstructured text data aided by software that can identify concepts, patterns, topics, keywords, and other data attributes. This is also called text analysis, although some distinguish between the two terms; In this view, text analytics refers to an application that uses text mining techniques to sort datasets. Text mining and analysis helps organizations find potentially valuable business information in company documents, customer emails, call center logs, literal survey comments, social network posts, medical records, and other textual data sources. Increasingly, text mining capabilities are also being incorporated into AI chatbots and virtual agents that companies are deploying to provide automated responses to customers as part of marketing, sales, and customer service activities.

Text mining is similar in nature to data mining, but focuses on text instead of more structured forms of data. However, one of the first steps in the text mining process is to organize and structure the data in such a way that it can be subjected to both qualitative and quantitative analysis. This usually involves the use of natural language processing (NLP) technology, which uses computational linguistics to analyze and interpret data sets.

2. Text mining

Text mining software uses natural language processing (NLP) along with rule-based systems and machine learning to uncover hidden relationships, patterns, and sentiments in text documents (Figure 1). Unstructured text is preprocessed using NLP.

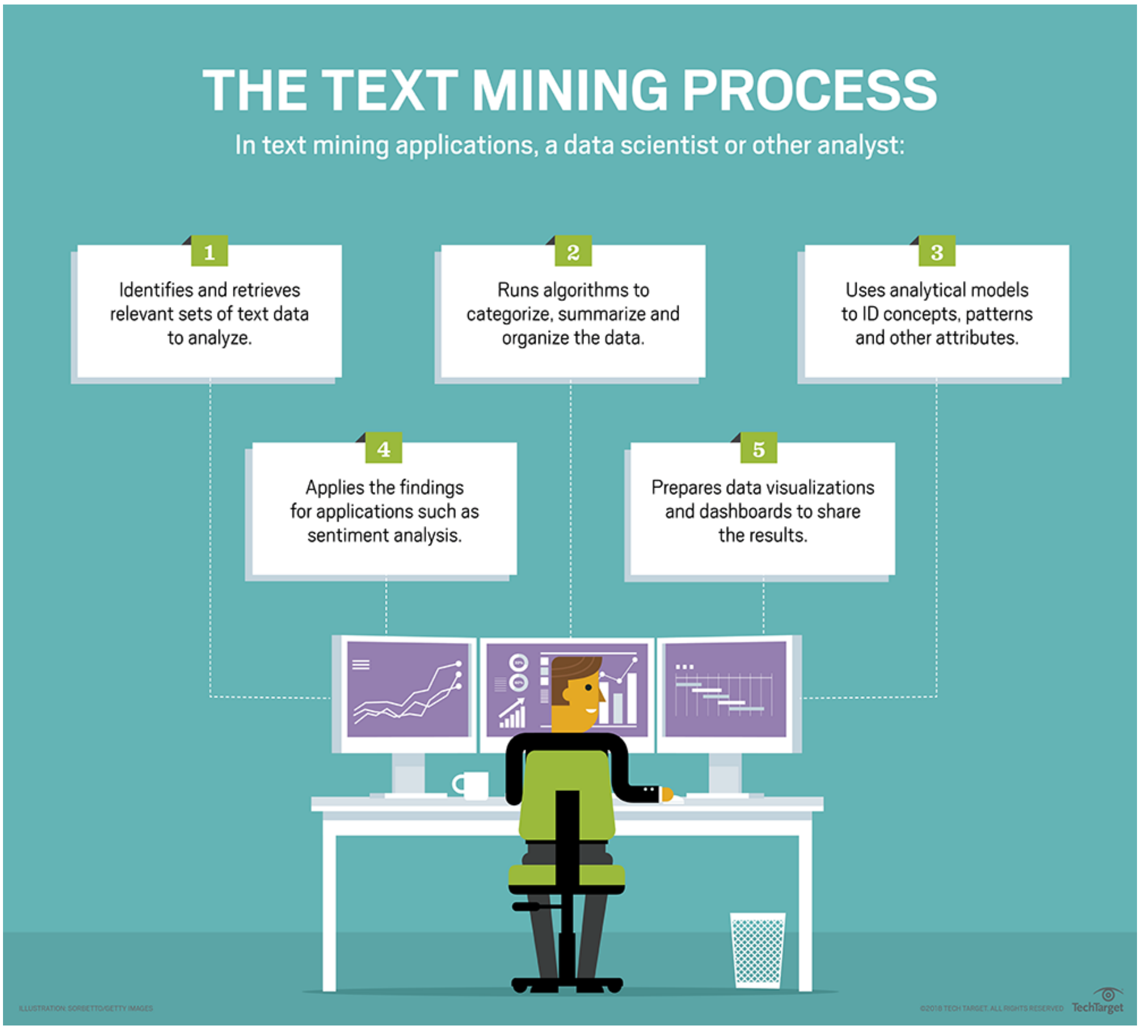

Figure 1. Key steps in text mining applications.
Source: *What is text mining (text analytics)?* C. Stedman, 2023, pobrano z: https://www.techtarget.com/searchbusinessanalytics/definition/text-mining (access: 10.05.2023).

Preprocessing can include any of the following steps (Dantoni, 2022):

- Cleaning: – removing small words (for example, in English they are a, an, the) and correcting spelling mistakes. As a result, the word is reduced to its root by removing prefixes and suffixes (for example, "hire" is the root for both "hiring" and "hired").
- Tokenization: – dividing text into separate words and phrases.
- Marking parts of speech: – identifying parts of speech in the text, such as nouns, verbs and adjectives.
- Analysis syntax: – analysis of the structure of sentences and phrases to determine the role of different words. For example, it identifies the subject, verb, and object of a sentence.

The data prepared in this way is ready for the use of machine learning models that identify patterns and relationships in documents. Each machine learning model must first be trained by providing it with documents that have been manually marked as belonging to a specific category or containing a specific sentiment.

Figure 2 illustrates this process. Text mining software first pre-processes a text document using NLP and then feeds it into a predictive model built using training data. The model assigns a category tag to the document. Depending on the category, the document may be redirected to the appropriate operating procedure or to text analysis software. For example, if the system analyzes the emails sent by customers to the company's customer service email address, and the model assigns a tag "defective product", the email may be forwarded to the quality assurance department to investigate the problem.

Text analytics software can also examine flagged emails to determine the percentage of delivered products that are defective.

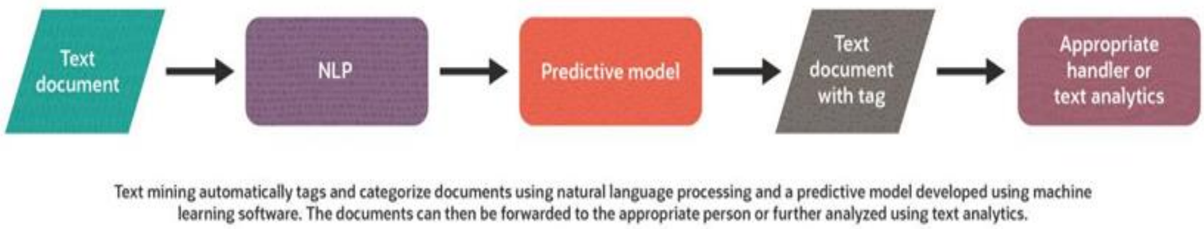

Figure 2. Text mining scheme.
Source: *What Is Text Mining & How Does It Work?*, J. Dantoni, 2022, retrieved from: https://www.netsuite.com/portal/resource/articles/data-warehouse/text-mining.shtml (access: 10.05.2023).

3. Industry 4.0

Industry 4.0 is the term used to describe the fourth industrial revolution: digitization and automation of production. We are in the midst of a fundamental change in the way products are manufactured, and this is deeply related to the future of the Internet of Things (IoT) (Figure 33).

Figure 3. Industrial development.
Source: *An introduction to Industry 4.0*, C. Buchberger, 2023, retrieved from: https://www.emnify.com/blog/ industry-4-0 (access: 10.05.2023).

Advances in networking, machine learning, data analytics, robotics, 3D printing, and other technologies are making huge improvements to industrial processes and reducing our reliance on human labor and decision-making. Relying on digital solutions, manufacturing can reduce human error, shorten time-to-market and increase the speed at which industrial processes can adapt to new information (Figure 4).

Figure 4. Components determining the development of industry
Source: *An introduction to Industry 4.0*, C. Buchberger, 2023, retrieved from: https://www.emnify.com/blog/industry-4-0 (access: 10.05.2023).

There are many branches of technology that enable Industry 4.0. But they are all generally subject to four overarching principles:

- Interconnection,
- Transparency of information,
- Support,
- Decentralised decisions.

Machine-to-machine and machine-to-human communication is a key element of Industry 4.0. To make data-driven decisions and reduce our reliance on human labor, factories and industrial processes need rich integration between the hardware and software involved in manufacturing. The Internet of Things enables the use of this principle of interconnection. It enables manufacturers to collect information from their machinery and equipment and access it in a useful way through a database. Thanks to advances in network technology (especially in cellular IoT), it is possible to connect thousands of devices in a concentrated area and maintain reliable indoor coverage.

Traditional production is hampered by a lack of insight into production. People have to provide information and manually provide status updates. However, along the production line and throughout the product lifecycle, there are countless blind spots where operators simply don't have the data they need to make improvements and optimize processes. The interconnectedness of Industry 4.0 opens the door to transparency of information, enabling manufacturers to collect vast amounts of data at every stage of production. Using this aggregated information, operators can spot problems, inefficiencies, and opportunities that weren't seen before (Buchberger, 2023).

For complex processes that still require human decision-making, Industry 4.0 creates pathways for technology by providing alerts and notifications to identify failures, quality drops or weaknesses in the production cycle. Technologies such as augmented reality and cloud computing also allow organizations to create simulations and test environments, so they can identify problems before they become costly mistakes and develop solutions that they can deploy with confidence. Industrial technology can also support people in tasks that are difficult or dangerous. For example, maintenance is critical to maintaining consistent performance and maximizing equipment life. But traditionally, maintenance is more of a reactive process. Part of Industry 4.0 is the transition to predictive maintenance.

In production, over-reliance on manual decision-making creates a bottleneck: everything must be directed by the worker, and he can only make one decision at a time. If people are in a hurry to make these decisions, it can increase the error rate. AI-enhanced machines can recognize patterns and be configured to respond to data with the same choices a human would make.

4. Production management systems

MES (Manufacturing Execution System) systems, or production management systems, or as they are also often called, production execution systems, are systems that aim to provide the information needed to optimize all production operations – from the order process to the stage of delivery of finished products. Without them, it is difficult to imagine the functioning of a modern enterprise (Zielinski, 2023).

The MES class system is understood as an IT system using information technologies, including communication, control software, electronic devices and, importantly, elements of industrial automation, which enable effective collection of information in real time directly from production stations, and then their transfer to the company's business systems. All information on production is collected here, which can be automatically downloaded directly from machines, internal logistics systems of the company, automation systems, including the Industrial Internet of Things (IIoT) and with the participation of employees directly employed in production or in maintenance and logistics departments.

Currently, there is a tendency to enrich MRP IT systems with additional functions developing their analytical capabilities and extending the application of the MRP method to other areas of the company's activity, such as: financial management, distribution, sales, etc. Contemporary software producers, striving to maximally meet the needs reported by managers, supported by computer hardware with increasing computing capabilities, initiate the creation of systems integrating the functions of several previously independent systems. Such integration leads to a natural blurring of the boundaries between the highlighted systems.

5. Natural Language Processing Case Study

Natural language processing (NLP) is a key component of many data science systems that need to understand or justify text. Common use cases include answering questions, paraphrasing or summarizing, sentiment analysis, natural language analysis, language modeling, and disambiguation. The limitations of popular NLP libraries and the latest trends in the IT industry, prompted John Snow Labs, a global AI company, to develop the Spark NLP library – an open source natural language processing library, built on top of Apache Spark and Spark ML (John Snow Labs, 2023; Huge, 2019). Thiscase study uses the NLP Lab platform, dividing the work into stages.

6. Analysis – disambiguation of documents

Disambiguation is the result of a deep linguistic analysis (Figure 5):

- Detailed syntax to identify tokens, tags, parts of speech, phrases, and sentences;
- Full dependency tree;
- Term labels that indicate the exact meaning of each term in a sentence through the use of context.

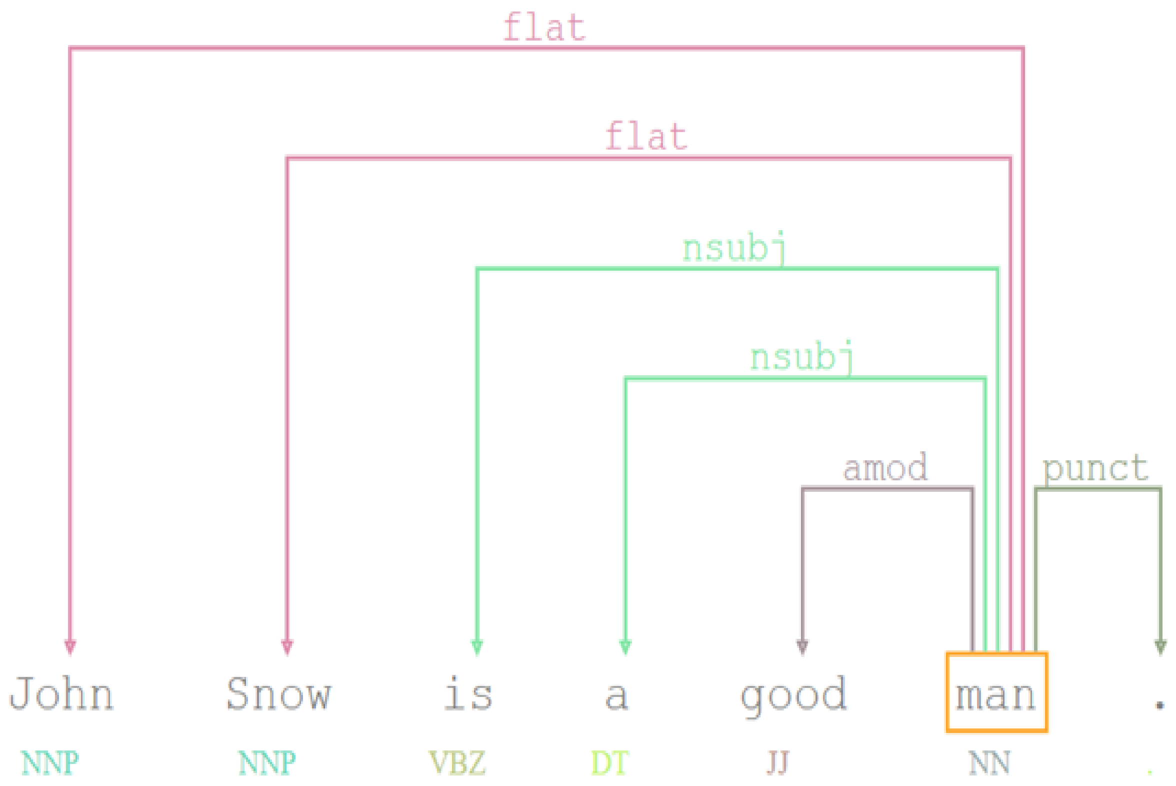

Figure 5. Clarifying documents.
Source: own study.

7. Document analysis – key elements

The key elements are the key lemmas, phrases, concepts of the Knowledge Graph (here called Syncons), sentences and topics of the Knowledge Graph found in the text, each with its relevance score (Figure 6).

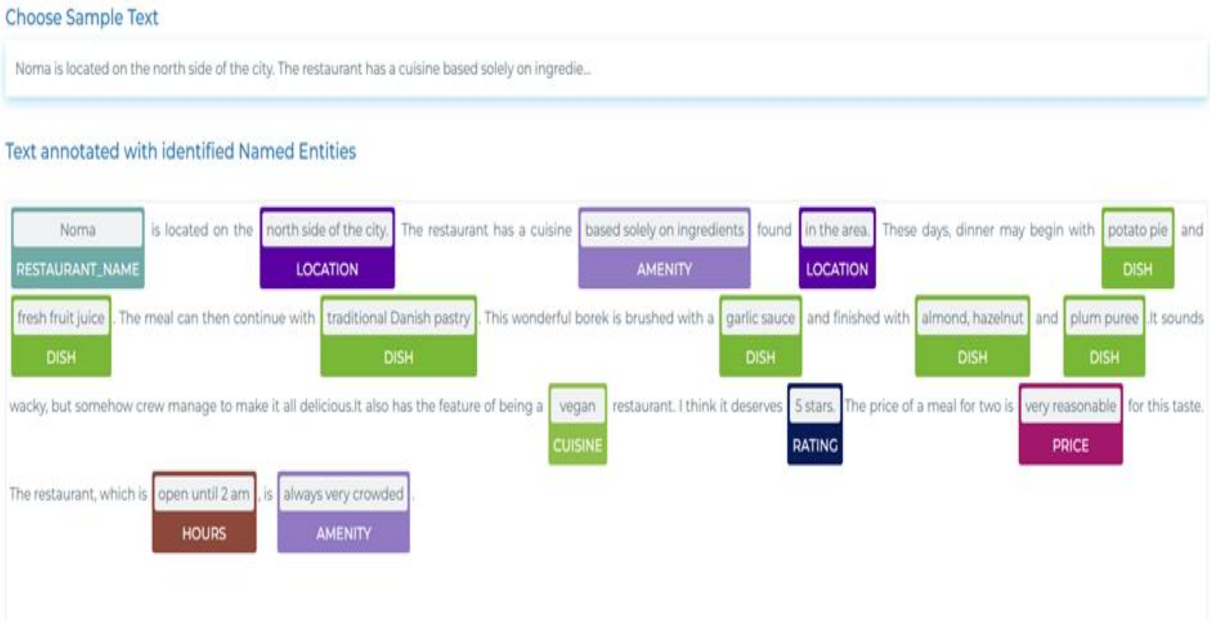

Figure 6. Key elements of documents.
Source: own study.

8. Analysis of documents – units

Named entities are the people, organizations, places, and values (such as currency amounts, percentages, and measures) listed in the text, with appropriate links to open data sources such as Wikidata, DBpedia, and GeoNames (
Figure *7*).

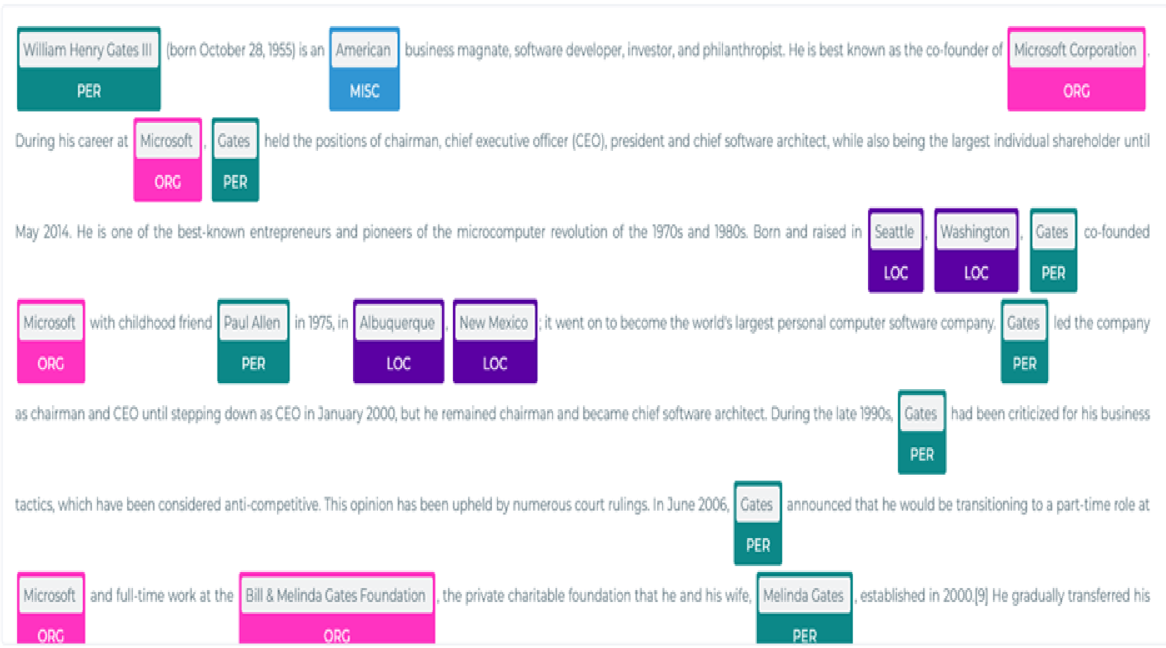

Figure 7. Analysis of units.
Source: own study.

9. Analysis – document relations

Relationships express the semantic role of terms related to the verb and help answer questions such as: "who did what, when?", "what caused what to whom?" etc. (Figure 8).

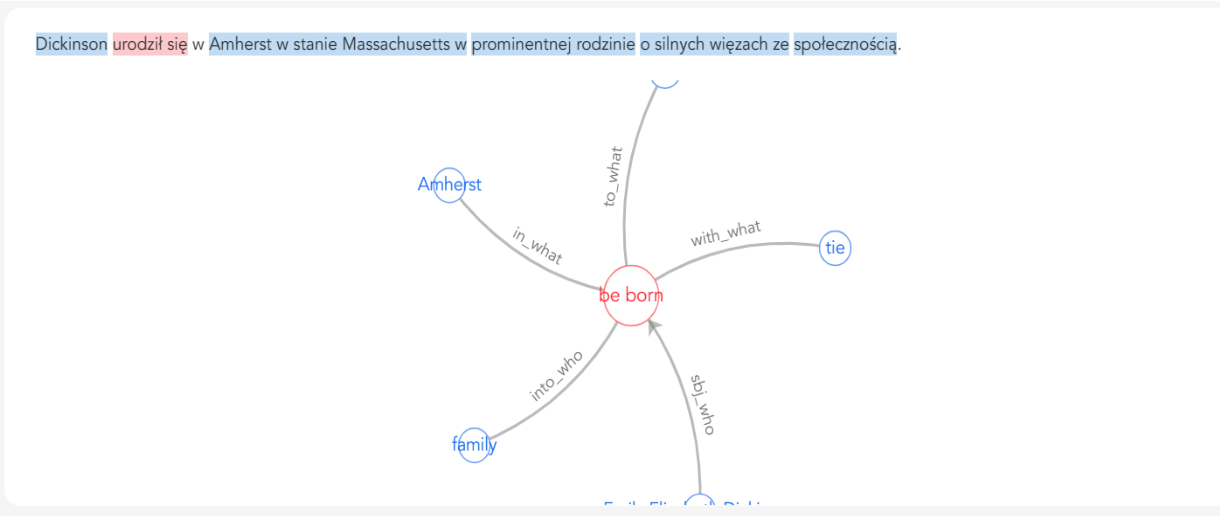

Figure 8. Document relations.
Source: own study.

10. Analysis – document tone

Sentiment is an indicator of how positive or negative the tone of a text is. It takes into account the internal positivity or negativity of the concepts expressed in the text and the relationships between concepts and other elements of the text, such as negations (Figure 9).

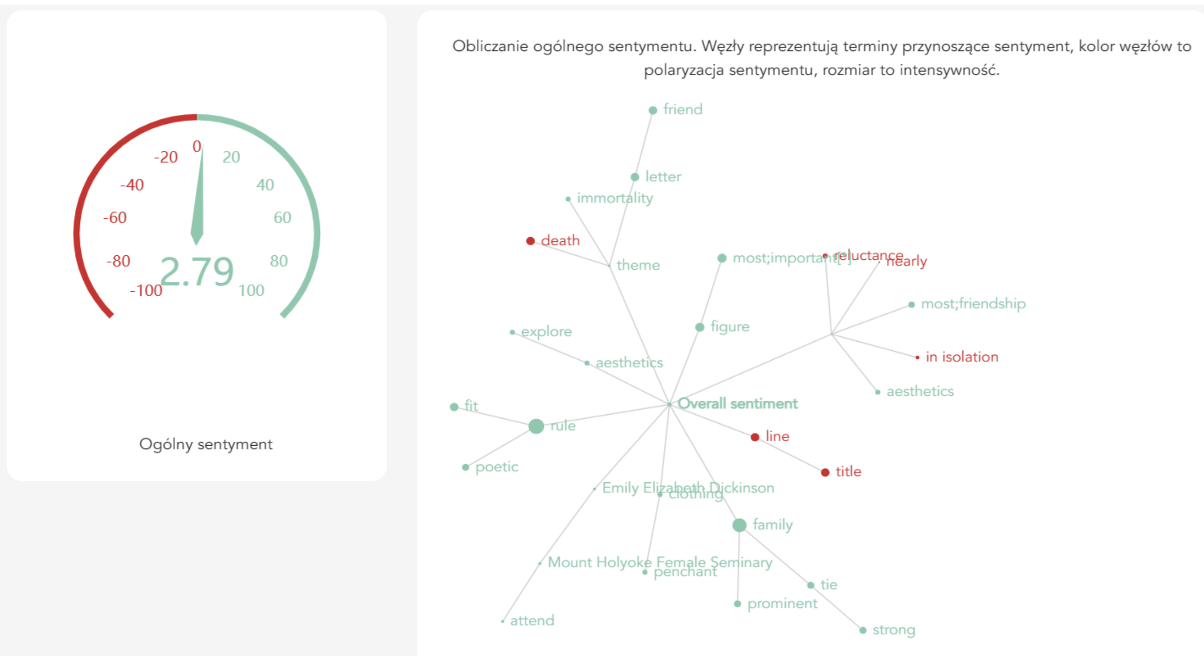

Figure 9. Tone of the document.
Source: own study.

11. Conclusions

The above types of analysis can be enriched by a rich set of linguistic and analytical modeling tools for discovering, extracting and predicting knowledge from many text documents. After transformation, the text can be used in Data Mining tools, themes and themes are identified as clear relationships. Documents described in this way can be combined into appropriate groups ready for exploratory analysis or modeling.

Interactive text mining allows you to find previously unknown patterns in document collections and apply them directly to predictive models, presenting them as part of an enterprise taxonomy or corporate dashboards – maximizing the value of acquired knowledge from all sources of information. This solution saves money and reduces resources by automating time-consuming tasks related to reading and comprehension. By consolidating structured data and textual information sources, you get a more accurate and complete picture of your organization.

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Concept of application of the semantic net in monitoring the production process

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Abstract: Semantic management of production processes is the use of semantic technologies such as ontologies, RDF, OWL, SPARQL, etc., to describe and manage production processes in a more precise, unambiguous and flexible way. With such ontologies, complex relationships between assets in the production process can be represented, allowing for better understanding and management of them. The article, on the example of the Modeling Laboratory of Intelligent Production Systems of the Kielce University of Technology, presents a semantic approach to the description of production processes.
Key words: Semantic Web, ontology, RDF, OWL, production management, FluentEditor.

1. Introduction

Semantic management of production processes is the use of semantic technologies such as ontologies, RDF, OWL, SPARQL, etc., to describe and manage production processes in a more precise, unambiguous and flexible way. The Semantic Web itself is a set of technologies and standards that enable data to be represented and made available in a structured, machine-readable format, allowing intelligent applications to analyze and use the data. With the use of semantic technologies, ontologies can be defined that describe production process models in a formal and unambiguous manner, taking into account the relationships between resources, process steps, production time and costs, product quality, etc. Based on these ontologies, information systems can be built that automate production processes, analyze and optimize the efficiency and quality of production, monitor the consumption of raw materials and energy, etc.

In the context of monitoring production processes, the use of semantic web technology can bring many benefits. One of the main benefits of using semantic web technology is the ability to represent and integrate data from different sources and formats. In the manufacturing process, data can come from a variety of sources such as sensors, machines, and human input. Representing data in a common, standardized format using semantic web technology facilitates data integration and analysis, providing a more complete picture of the manufacturing process. Another benefit is the ability to make inferences about data using semantic web technologies to apply rules and logic to data to identify patterns, anomalies, and correlations. This can enable early detection of potential problems or optimization opportunities, allowing for more efficient and effective production processes.

However, Semantic Web technologies can also enable more effective communication and collaboration between the various stakeholders involved in the production process. By ensuring a common understanding of data, stakeholders can more easily exchange information, coordinate activities, and make data-driven decisions. One of the key challenges in monitoring production processes is the large amount of data generated by various sensors, machines and systems, which can be difficult to integrate and analyze. Semantic web technologies can help meet this challenge by providing a standard way to represent and organize data, as well as a set of tools and methods to infer and extract knowledge from it.

One approach to using semantic web technology in monitoring production processes is to use a semantic data model that captures the relevant concepts, relationships, and constraints in the domain. This data model can be used to represent various aspects of the manufacturing process such as machines, products, materials, operations and quality control measures, and is written using controlled natural language.

Controlled Natural Language (CNL) (Schwitter, 2010)is a natural language that has been specifically designed and constrained to be easily understood by humans and unambiguously interpreted by computers. A CNL is typically created by specialists in a particular field who wish to ensure accurate and precise expression of their knowledge while avoiding ambiguities and interpretation errors. Controlled natural language is usually based on natural language grammar and vocabulary, but may also include specialized terms and abbreviations that are specific to the field.

In CNL, complicated syntax is usually avoided, and sentences are short and simpler in structure than in natural language. The CNL is also often devoid of ambiguity and underdetermination to allow accurate and unambiguous interpretation by computers. Controlled natural languages are often used in various fields such as medicine, law, finance, life sciences, engineering and others. An example of a CNL would be SPARQL (Apache Jena, 2023), used to query the Semantic Web, or SCL (Specification and Description Language) (Wikipedia SDL, 2023), used in software engineering to describe system requirements.

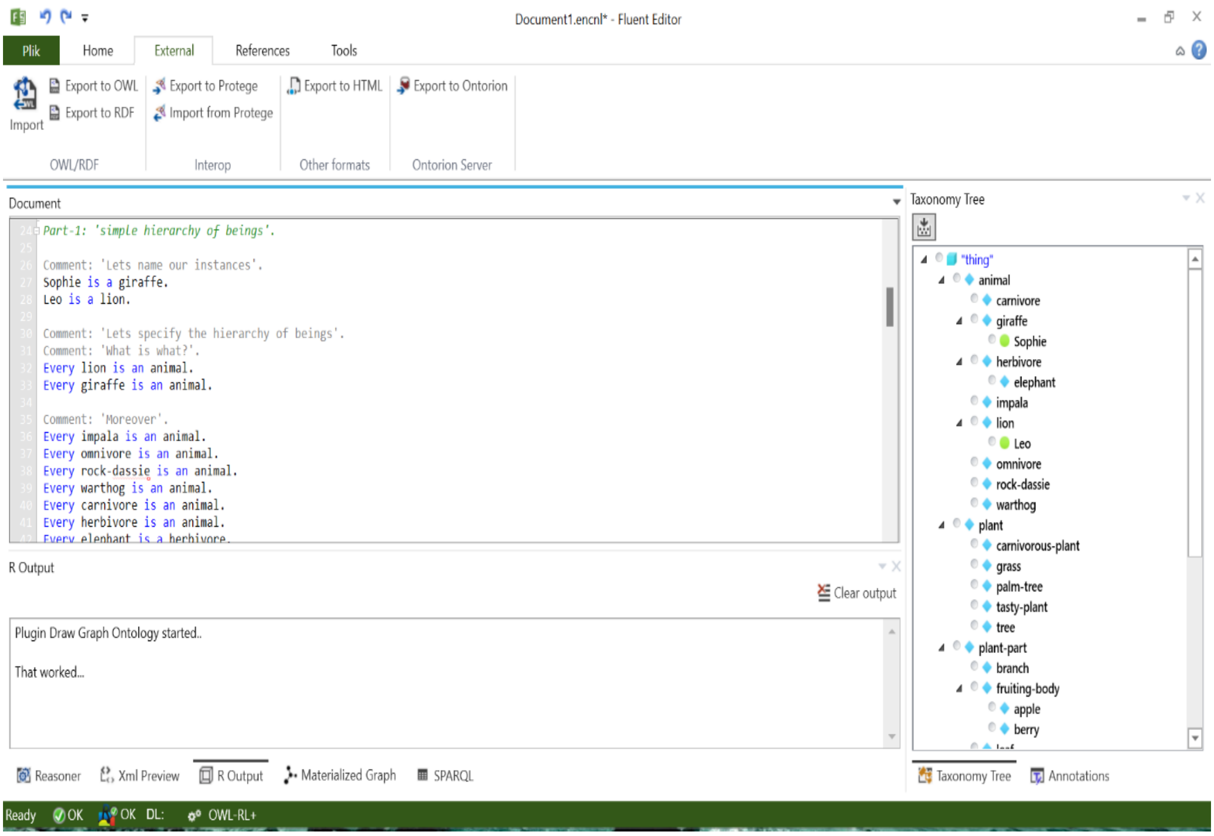

Figure 1. An example window of the Fluent Editor program.
Source: own elaboration.

One of the CNL editors used to build ontologies is Cognitum (Cognitum , 2023)'s FluentEditor, which was designed for a user-friendly development environment. FluentEditor allows you to easily edit sentences understandable to users who are not fluent in English. Visually, the editor is similar to Microsoft Office, has a ribbon and customizable windows. The built-in graphics engine edits high-quality ontology diagrams as shown in Figure . The Fluent Editor works with the Protégé editor, allowing you to take full advantage of their capabilities. Fluent Editor also has a built-in mechanism that allows you to monitor the modelling process. A helpful attribute is highlighting text that contains potential errors and prompts you to edit the words.

The use of a semantic data model enables the integration of data from various sources and systems, such as ERP (Enterprise Resource Planning), MES (Manufacturing Execution System) and SCADA (Supervisory Control and Data Acquisition) systems based on common ontologies and data exchange standards. Thanks to this, you can get a complete and unambiguous picture of production processes, which allows you to quickly respond to failures and problems, as well as optimize production processes in real time. As a result, semantic management of production processes contributes to improving the quality of products, reducing production costs, increasing the efficiency and effectiveness of production processes, as well as improving the overall competitiveness of the company on the market. It also allows you to create semantic annotations and metadata that provide additional information about the data, such as its origin, quality and suitability for various tasks and uses. Another important aspect of the use of semantic web technology in monitoring production processes is the use of semantic inference and inference techniques. The use of semantic inference and inference techniques allows for the automatic generation of new information based on existing data and logical rules.

Semantic inference is the use of ontologies and rules describing relationships between assets to automatically infer new facts from existing ones. For example, based on the manufacturing process ontology, it can be inferred that if a manufacturing process takes more than 10 hours, the cost of production is likely to increase. This allows you to automatically monitor production processes and generate alerts when production costs exceed a certain level.

Inference techniques, such as deductive, inductive, or abductive inference, allow new inferences to be automatically generated based on already existing data and knowledge. For example, from data on raw material consumption and production time, it can be inferred that certain steps in the production process are inefficient and need to be optimised. This allows you to automatically identify problems and identify potential solutions.

Semantic reasoning and inference techniques have applications in many fields, including the management of production processes. They allow for the automation of decision-making processes, optimization of production processes, detection of errors and problems, as well as the generation of new information and knowledge, which contributes to improving the quality of products, increasing the efficiency and effectiveness of production processes and improving the overall competitiveness of the company on the market. These techniques enable the extraction of knowledge from data, e.g. identifying patterns, correlations and anomalies in the production process, predicting the behaviour of machines and processes, and optimizing the production plan and schedule.

The Semantic Web allows data to be represented in standard formats such as RDF (Resource Description Framework), OWL (Web Ontology Language) and SPARQL (SPARQL Protocol and RDF Query Language). Data represented in these formats is easy for machines to interpret and allows semantic associations between different types of data.

Data can be represented in RDF (Resource Description Framework) and OWL (Web Ontology Language) formats as follows:

- RDF format:

```
< rdf:RDF xmlns:rdf = "http://www.w3.org/1999/02/22-rdf-syntax-ns#"
        xmlns:dc ="http://purl.org/dc/elements/1.1/">
< rdf:Description rdf:about ="http://example.org/book">
< dc:title >The Semantic Web</ dc:title >
< dc:creator >Tim Berners-Lee</ dc:creator >
< dc:date >2001-05-17</ dc:date >
</ rdf:Description >
</ rdf:RDF >
```

This RDF code represents a book called "The Semantic Web", written by Tim Berners-Lee and published on May 17, 2001.

- OWL Format:

```
< rdf:RDF xmlns:rdf = "http://www.w3.org/1999/02/22-rdf-syntax-ns#"
        xmlns:rdfs ="http://www.w3.org/2000/01/rdf-schema#"
        xmlns:owl ="http://www.w3.org/2002/07/owl#">
< owl:Class rdf:about ="http://example.org/Animal">
< rdfs:label >Animal</ rdfs:label >
</ owl:Class >
< owl:Class rdf:about ="http://example.org/Mammal">
< rdfs:label >Mammal</ rdfs:label >
< rdfs:subClassOf rdf:resource ="http://example.org/Animal"/>
</ owl:Class >
< owl:Class rdf:about ="http://example.org/Dog">
< rdfs:label >Dog</ rdfs:label >
< rdfs:subClassOf rdf:resource ="http://example.org/Mammal"/>
</ owl:Class >
< owl:NamedIndividual rdf:about ="http://example.org/MyDog " >
< rdf:type rdf:resource ="http://example.org/Dog"/>
< rdfs:label >My Dog</ rdfs:label >
  </ owl:NamedIndividual >
</ rdf:RDF >
```

This OWL code represents a taxonomy of animals, with a hierarchy of classes Animal, Mammal, and Dog. The code also includes a named person, " MyDog ", who is a Dog type. The rdfs:label property is used to provide a human-readable label for classes and entities.

As already mentioned in the case of monitoring production processes, data can come from various sources, such as sensors, machines and people. The use of the semantic web allows this data to be represented in a uniform, standardized format, which facilitates their integration and analysis. For example, temperature, humidity, pressure, and production speed data can be represented in RDF format, and information about the machines that generate this data can be represented in OWL format. Thanks to this, semantic connections can be made between different types of data, which allows for a more comprehensive analysis of production processes.

Information extraction from RDF and OWL data can also be performed using SPARQL, which allows searching and retrieving data from RDF graphs and OWL ontologies. Thanks to this, you can easily and quickly search for information about production processes, e.g. detecting machine failures, analyzing production data to optimize processes or identifying relationships between various factors affecting product quality.

For example, if we want to know the temperature values from sensors in a specific location at a specific time, we can use a SPARQL query that will return the appropriate results. This query might look like this:

```
SELECT ? temperature

WHERE {

?sensor rdf:type : TemperatureSensor .

  ?sensor :location :Factory1 .

?sensor :value ?temperature .

?sensor :timestamp ?time .

FILTER (?time >= "2022-01-01T00:00:00Z"^^ xsd:dateTime && ?time <=
"2022-01-31T23:59:59Z"^^ xsd:dateTime )

}
```

In this example, the SPARQL query searches the RDF graph for all temperature sensors (`?sensor rdf:type : TemperatureSensor`) at location "Factory1" (`?sensor : location :Factory1`) and returns their values (`?sensor : value ? temperature`) and the measurement time (`?sensor : timestamp ? time`), which must be between January 1, 2022 and January 31, 2022 (`FILTER (? time >= "2022-01-01T00:00:00Z"^^ xsd:dateTime && ? time <= "2022-01-31T23:59:59Z"^^ xsd:dateTime )`).

SPARQL queries also allow you to perform more advanced operations such as data aggregation, result filtering, query merging, and more. Thanks to this, they enable effective extraction of information from data in the RDF and OWL format, which is useful in monitoring production processes.

SPARQL allows you to perform various data manipulations that allow for more advanced processing of RDF graphs and OWL ontologies. Below are some examples of the most commonly used operations in SPARQL.

1. Data aggregation – SPARQL allows you to calculate the sum, average, minimum and maximum values of numerical attributes from query results. For example, if we want to calculate the average temperature from sensors in a specific location, we can use a query with the `AVG() function` :
```
SELECT AVG(?temperature)
WHERE {
?sensor rdf:type : TemperatureSensor .
?sensor :location :Factory1 .
?sensor :value ?temperature .
}
```
2. Filtering results – SPARQL allows you to filter results based on specific criteria. For example, if we want to find sensors whose temperature value exceeds 30 degrees, we can use a query with the `FILTER() function`:
```
SELECT ?sensor ?temperature
WHERE {
?sensor rdf:type : TemperatureSensor .
?sensor :location :Factory1 .
?sensor :value ?temperature .
 FILTER (? temperature > 30)
}
```
3. Query merging – SPARQL allows you to combine several queries into one, which allows for more complex and flexible data processing. For example, if we want to find sensors whose temperature value exceeds 30 degrees and at the same time their humidity is at least 50%, we can use a query with combining two conditions using the `AND operator` :
```
SELECT ?sensor ?temperature ?humidity
WHERE {
?sensor rdf:type : TemperatureSensor .
?sensor :location :Factory1 .
?sensor :value ?temperature .
?sensor2 rdf:type : HumiditySensor .
?sensor2 :location :Factory1 .
?sensor2 :value ?humidity .
 FILTER (? temperature > 30 && ? humidity >= 50)
}
```

Thanks to these operations, SPARQL enables effective extraction of information from data in RDF and OWL format, which is useful in monitoring production processes. RDF (Resource Description Framework) and OWL (Web Ontology Language) data are represented as directed graphs, which consist of vertices and edges. Vertices represent resources such as objects, classes, attributes, and relationships between them. The edges represent the relationships between assets and their properties.

In RDF, vertices are identified by unique URIs (Uniform Resource Identifiers), which are used to uniquely distinguish resources. Edges, on the other hand, connect vertices and are marked with a property name that describes the relationship between them. For example, if we want to describe that a given product is part of a certain order, we can create three vertices: product, order, and a relationship between them, and then connect them using the " isPartOf " or similar property.

In the OWL format, graphs represent ontologies, i.e. systems of defined concepts and relationships between them. OWL ontologies allow you to create a hierarchy of classes, subclasses and properties, as well as define constraints and axioms. As a result, they allow you to describe advanced relationships between resources, such as relationships between products, production processes, employees, etc.

Describing advanced relationships between assets, such as relationships between products, production processes, and employees, is possible with OWL ontologies. OWL allows you to define a hierarchy of classes, subclasses, and properties, which makes it possible to describe complex relationships between resources. For example, in the OWL ontology for the production process implemented in the Intelligent Production Systems Modeling Workshop (

Figure), you can define the " Production Process " class , and then subclasses such as " Series ProductionA " , " Series ProductionB ", etc. Each of these subclasses can have its own properties such as " Production Time " , " Production Cost ", etc. (Figure 3). In this way, we can describe different production processes and compare them with each other on the basis of different criteria.

Figure 2. The production line in the Modeling Studio of Intelligent Production Systems of the PŚk. Source: own elaboration.

Similarly, in the OWL ontology for employees, you can define a class "Employee" and then subclasses such as " Production Worker " ," Warehouse Worker " , etc. Each of these subclasses can have its own properties, such as "First Name" , "Last Name" ,"Job Title" " , etc. We can also define relationships between employees and production processes, for example, the relationship " Employee ExecutingProcess " that connects employees to the production processes they work on. Thanks to such ontologies, complex relationships between resources in the production process can be represented in an unambiguous and flexible way, which allows for better understanding and management of them.

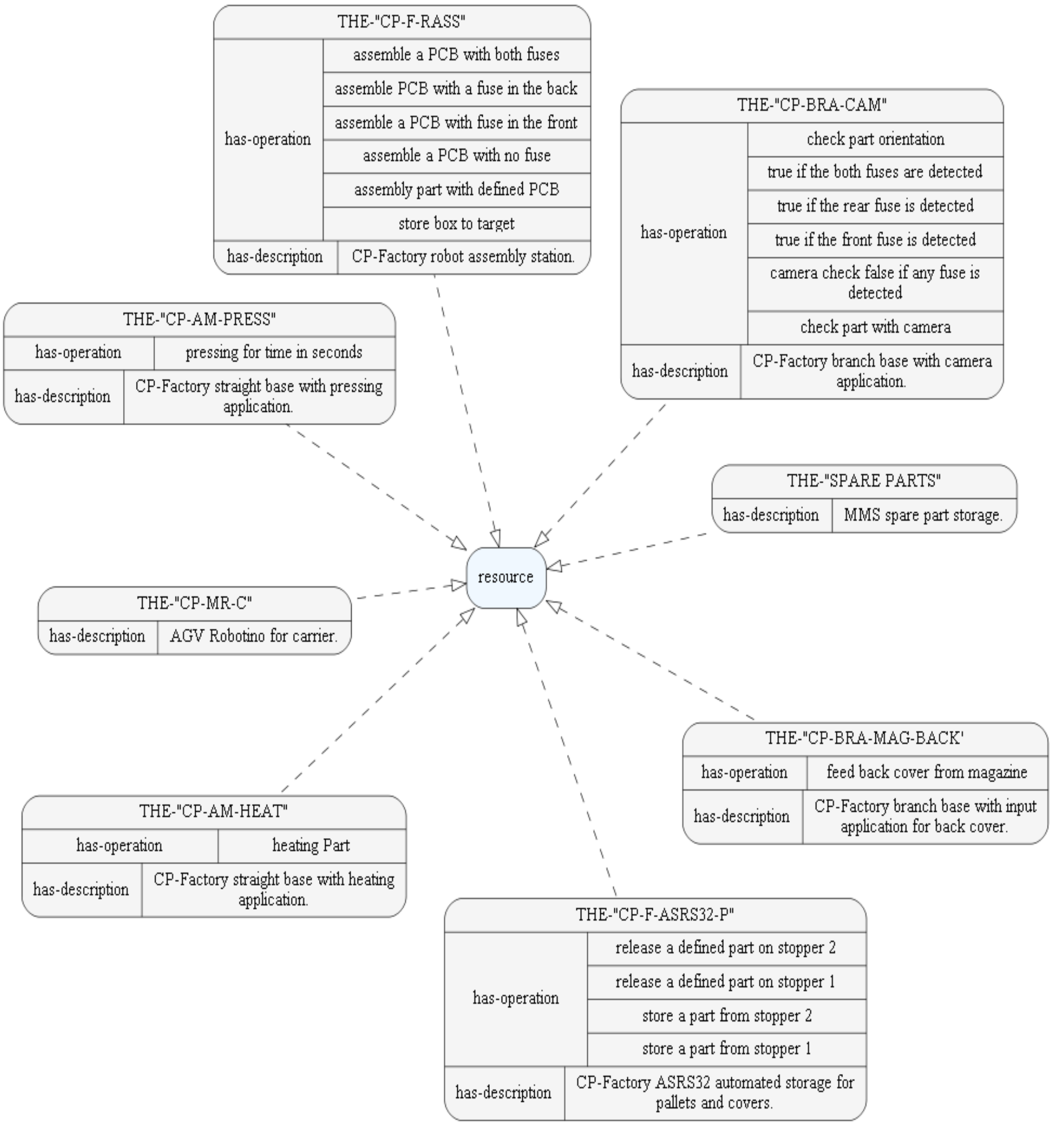

Figure 3. An example of an ontology for describing production machines.
Source: „Semantic product personalization based on the CogniPy environment", D. Dobrowolski, J. Świątkowski, 2022, *Scientific Papers of Silesian University of Technology – Organization and Management Series*, pp. 141-152.

2. Conclusions

The use of semantic web technology in the monitoring of production processes can bring significant benefits in terms of data integration, analysis and communication, leading to more efficient and effective production processes. The Semantic Web is a vision of the web where data is structured in a way that allows computers to understand its meaning and context, making it easy to share, reuse, and integrate information across applications and domains. The use of semantic web technology in the monitoring of production processes can bring significant benefits in terms of efficiency, productivity and decision making.

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Assessment of weld quality in bridge construction procedures

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Abstract: This study concerns an important issue of welding bridge steelwork and their structural strength assessment. Such constructions must be characterised by certain structural strength in varied weather conditions. The problem of contamination of areas to be welded is very important because they are welded in the natural environment. Tests were conducted using a ZWICK Z100 tensile testing machine in room temperature and in the temperature increased to 1200°C. The samples were prepared according to standards applicable to bridge structures. The tests conducted enabled to assess: tensile strength, bending strength, plasticity, maximum tensile strength breaking the welded joints and their elongation.

The stainless construction steel samples were cut using laser, plasma and plasma with cleaned and bleached edges and the tests were conducted in two groups: cleaned and not cleaned The cleaned plasma-cut samples had the highest tensile strength.

Bridge constructions must be designed and constructed in the manner which ensures their strength, service life and user safety. Therefore, bridge structures are subject to rigorous testing and inspections to ensure their quality.

Welding is one of the most important processes used in bridge manufacturing and assembling. Welded joints can transfer high loads and forces, which is necessary for bridge user safety. Welding bridge structures must be performed by highly qualified and experienced welders who use the latest welding techniques and methods. Welders must also observe strict quality standards to ensure that welds are durable and safe. Assessing weld quality using is non-destructive and destructive tests also important in order to ensure that welds comply with required quality standards. Such tests can help detect weld defects and remove them before bridge commissioning.

In conclusion, bridge construction welding is extremely important for bridge user safety and it requires application of the best practices and quality standards.

Key words: welding, butt welds, strength, elastic range, preparation.

1. Introduction

Since ancient times people have attempted to combine metals. As early as around 1000 BC, metals were combined by heating and exerting pressure. In Antiquity and in the Middle Ages, blowers and bellows were used to join metals with a low melting point, while forge welding was used to join elements made of bronze, copper, brass, silver or gold. The first soldering techniques were already known in the Middle Ages. However, it was only the development of welding that made it possible to combine different metals. The electric arc was first produced by Humphry Davy in Great Britain in 1800, and in 1881 it was used to join lead plates. This method was patented in 1885. Electric and gas welding methods were introduced in the late 19th century. An important event in the development of welding was the discovery of calcium carbide, called carbide, and the construction of an oxy-acetylene burner. Metal arc welding technology was also developed and coated electrodes were introduced.

At present, welding is the basic method of joining metals which is widely used in many industries. However, the safety of welded structures, as well as their proper operation, is influenced by the quality of the welds. Improperly welded joints and their poor quality directly affect time and financial losses, and may also contribute to the emergence of various types of hazards. Due to the fact that the welded joint is characterized by different properties than the original matter, it has not only a different structure, but also a diverse chemical composition. The quality of welds is also negatively affected by the introduced heat and additional materials used in welding processes. For this reason, it is very important to conduct weld tests, the purpose of which is to check the correctness of their execution.

The aim of this study is to assess the quality of welds in the procedures for the manufacture of bridge structures. The scope of the paper includes the characteristics of bridge structures and a description of welding processes. The organization of production taking into account welding non-conformities as well as the organization of quality control of welding works are presented. Non-destructive testing methods and types of welding non-conformities are characterized. An economic analysis of the implementation of butt joints of type V and X was also carried out. At the end of the paper, conclusions concerning the analysis of problems related to the testing of the quality of welded joints were presented.

2. Characteristics of bridges

A bridge is a structure which is intended to provide passage for a road, an independent pedestrian or pedestrian-bicycle route, a migration trail for wild animals or other types of passage over a terrain obstacle. The following are considered as bridges:

- bridge structures over water obstacles,
- movable bridge objects,
- folding bridge structures,
- viaducts over roads and valleys,
- half-bridges used in roads running along mountain slopes,
- flyovers,
- footbridges (Figure 1).

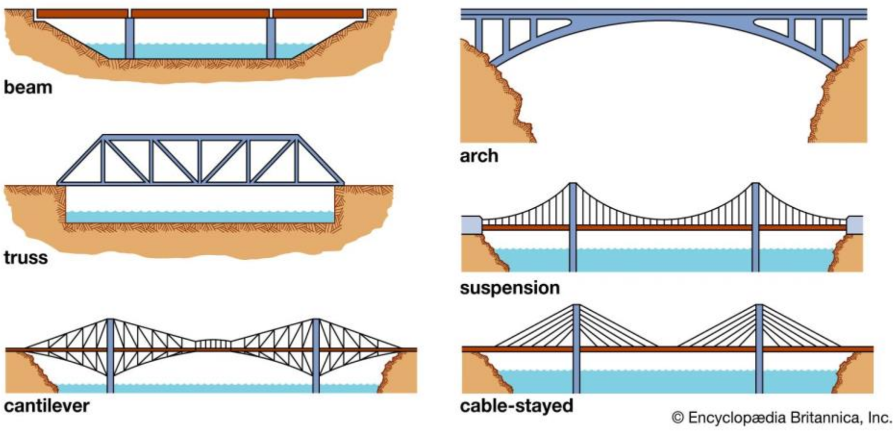


Figure 1. Types of bridges.
Source: https://mlodytechnik.pl/technika/30245-mosty-jak-lepiej-dbac-o-ich-bezpieczenstwo (access: 10.05.2023).

3. Welding processes

Welding is a branch of technology. It deals with processes that are associated with the permanent bonding of metals and their alloys. During the joining process, heat is applied to the place where the joint is formed. The basic welding processes are welding, soldering and bonding.

Welding is a method that is used to join metals. It consists in local heating of the metal to the melting point and it is carried out without applying pressure. A diagram of the weld formation process is shown in the figure below (Figure 2).

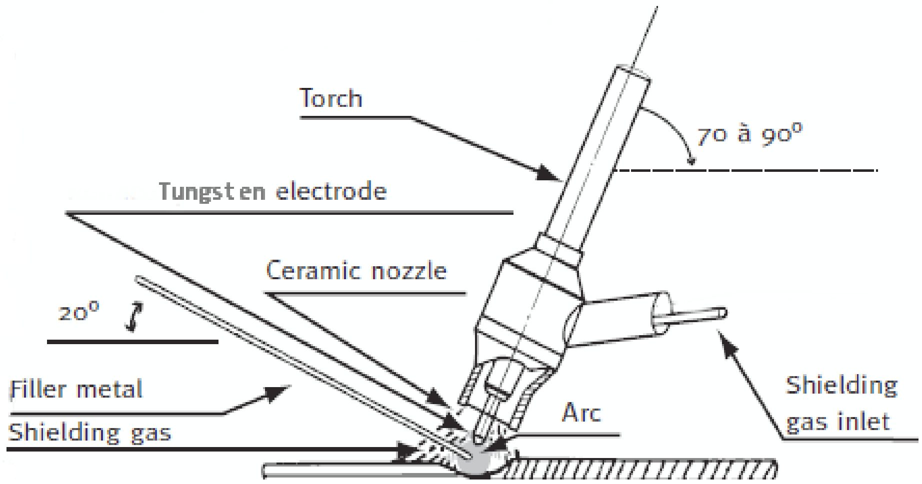


Figure 2. The principle of arc welding with a tungsten electrode in a gas shield.
Source: https://www.sciencedirect.com/topics/engineering/gas-tungsten-arc-welding (access: 10.05.2023).

Weldability is influenced not only by the type of welded material, but also by auxiliary material and the welding method used. It must therefore be considered as:

- metallurgical weldability,
- technological weldability,
- structural weldability.

Cracks are one of the disadvantages which constitute a completely unacceptable welding defect, disqualifying the joint. They pose a special threat to the use of the welded structure, which is evidenced by the fact that no standards and regulations accept detected cracks. The causes of cracks are attributable to the base material, auxiliary welding materials, welding processes and technologies, construction solutions, quality of workmanship, load conditions, and weather conditions during operation.

Taking into account the nature of scrap metal created as a result of decohesion (destruction) of the material under loads, a conventional division of solids into: plastic, elastic-plastic and brittle was introduced. The conventionality of the terms "brittleness" or "plasticity" results from the fact that they are not permanent characteristics or physical and chemical properties of materials under given thermodynamic conditions. Brittleness, and therefore its opposite, plasticity, should be understood as a characteristic of the behavior of a solid depending not only on its chemical composition, structure, physical and chemical properties of the surface and geometry of the shape, but also, last but not least, on the rate of deformation, the state of stresses and temperature.

4. Economic analysis of type V and X butt joints made– strength tests of welded joints

Samples for strength tests of welded joints were prepared according to ISO 4136:20212, for sheets 3 mm thick and more (Figure 3). The tests were conducted in the same conditions, the measurements were calculated according to the program entered in the machine, and the samples were welded using the TIG method.

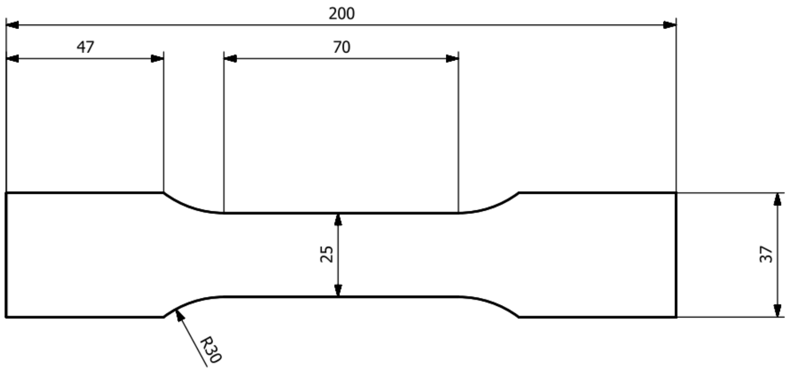
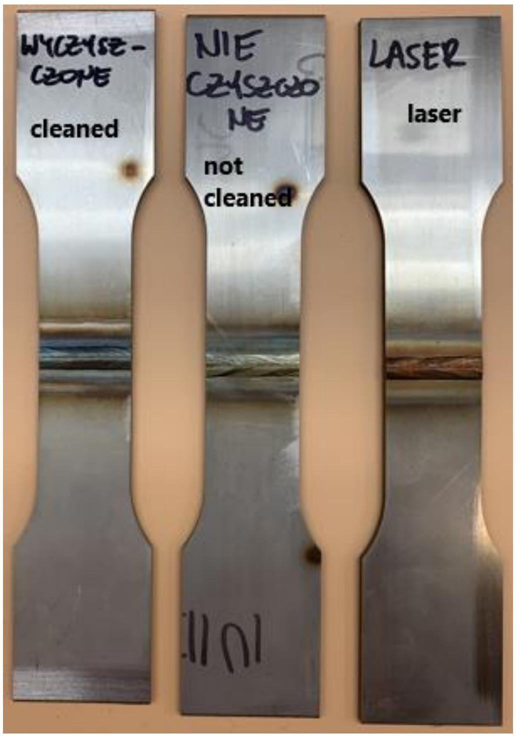


Figure 3. Dimensions of the samples to be used in the strength test according to ISO 4136:20212.
Source: own elaboration.

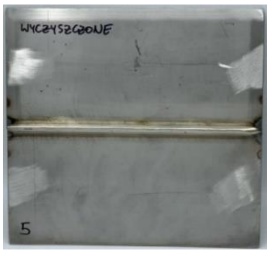
Samples from welded sheets were cut by electrical discharge machining using a electro EDM machine with a wire electrode. For strength tests, three samples of sheet metal were prepared: laser cut, sheets cleaned after plasma cutting, and sheets not cleaned after plasma cutting (Figure 4, Table 1).

a 

b 

Figure 4. Views of samples used in static tensile testing, (a) pre-rupture view of samples, (b) post-rupture view of samples.
Source: own elaboration.

Table 1
Comparison of the edges of sheets cut by different methods

CUTTING TECHNOLOGY	EDGE VIEW	
Laser		
Plasma		
Plasma and then bleaced		
EDGES	**FACE**	**ROOT OF WELD**
Bleached		
Not cleaned		
Cleaned		
After laser cutting		

Source: own elaboration.

The strength of welded joints was determined based on a single-axis static tensile test according to the PN-EN ISO 6892-1 2010 standard. The test was conducted using the Zwick/Roell Z100 testing machine. Table below presents the mechanical parameters of the tested welds (Figure 5, Table 2, Figure 6).

Figure 5. Sample mounted on Zwick/Roell Z 100 ripper. View after rupture.
Source: own elaboration.

Table 2
Mechanical parameters of welded joint sheets

Sheet metal type	Tensile strength Rm [MPa]	Maximum joint breaking force [kN]	Elongation [mm]
1. Cleaned	685	51.4	51
2. Not cleaned	679	50.9	48.1
3. Laser	669	50.2	51.4

Source: own elaboration.

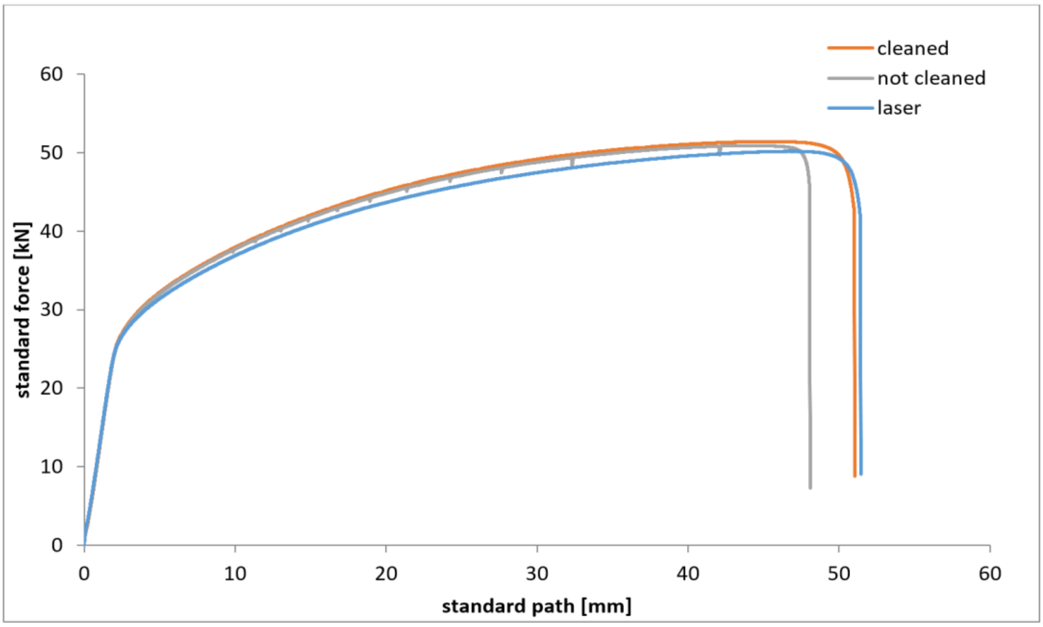


Figure 6. Overview of the mechanical properties of tested welds.
Source: own elaboration.

Preparation of the material before welding is very important for bridge structures, as it has a direct impact on the quality of the welded joint and on the durability and strength of the entire structure. Several factors that need to be considered when preparing the material before welding are:

- Cleaning – before welding, the material should be thoroughly cleaned of any impurities, such as rust, paint, oil, grease, etc. These contaminants can cause defects in welds and reduce the strength of the structure.
- Alignment and fit – structural elements should be precisely aligned and fitted before welding to ensure an even load on the entire structure and avoid stresses.
- Removing burrs – before welding, remove any burrs and surface irregularities that may affect the quality of the welded joint and cause cracks or warping of the structure.
- Weather conditions – welding should be carried out in appropriate weather conditions, such as lack of moisture, low air humidity, lack of wind, etc. These conditions will help prevent corrosion and increase the durability of the structure.

5. Conclusions

The basic performance characteristic – regardless of the source of classification – is mechanical strength, mainly yield strength Re, which determines the load-bearing capacity of the structure and its weight. In addition to satisfying strength requirements, they must also meet technological requirements, including good weldability, which guarantees reliable welded joints during their manufacture and operation, including resistance to hot, cold, lamellar and brittle fracture, with the required ductility and hardness in the SWC. Good mechanical and technological properties are achieved through the appropriate chemical composition of the steel and its heat or thermomechanical treatment.

The second basic property of steels used for welded structures should be their resistance to brittle fracture. It is, unfortunately, diminished by the manufacturing processes of the structure, but to the greatest extent by a set of stress-structural factors in the joint, related to the thermal welding process.

All these factors are important because the welded joint must be accurate, strong and durable in order for the bridge structure to be safe and serve its purpose. That is why it is important to prepare the material before welding carefully and follow all required standards and procedures.

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Algorithm of chromatographic data separation

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Abstract: Nowadays, one of the important issues of machine learning is the processing of large data sets. The issues related to Big Data refer primarily to data sets that are too large or complex to be processed by the algorithms currently used in data analysis. The article presents an algorithm inspired by the method of chromatographic separation, which can be applicable to issues related to Big Data collections. Chromatography is a physicochemical separation method in which the separated components are divided between two phases: the stationary phase and the mobile phase moves in a specific direction. The different division of the components of the mixture between the two phases causes the differentiation of the migration speed of the individual components. As a result, it leads to variable concentrations of the separated components over time. The chromatographic data separation algorithm is based on the basic paradigm that the processed data string is a mixture of substances – chemical molecules with a chain structure, which ensures that the given vector will be processed by the chromatographic algorithm in accordance with the rules that occur in the real chromatographic system. The result of the presented algorithm will be the creation of a set of chromatographs, thanks to which it is possible to identify characteristic data sequences that belong to a given data vector and its classification. The article presents an algorithm for chromatographic separation of data, as well as examples of data classification. The paper shows that the proposed algorithm works well in classification, and in particular shows high efficiency in classifying a data stream of a heterogeneous nature, i.e. a stream containing graphic objects, text and numerical data.
Key words: signal processing, big data processing, data mining, big data classification.

1. Introduction

Nowadays, one of the important issues of machine learning is the processing of large data sets. The size of large data sets is constantly increasing, from initially several dozen terabytes, and now to many petabytes of data. In machine learning, the term Big Data primarily refers to data sets that are too large or complex to be processed by the traditional algorithms used so far for data analysis.

The term "big data" was introduced in the 1990s by John Mashey to popularize Big data usually includes data sets where the amount of data prevents the use of commonly used algorithms for this type of issues due to limitations on computation time and the need for operational memory.

In this article, an algorithm has been presented that may be applicable to issues related to Big Data collections. The algorithm is inspired by the method of chromatographic separation of substances, which is commonly and successfully used in analytical chemistry.

In the first chapter of this article, the principles of chromatography and the terms that are used to describe the methods used in chromatography will be discussed. In the second chapter, an algorithm for data classification will be presented, which is inspired by the principles of chromatographic separation of substances. In the following parts of the article, the results of calculations – classification for sample data sets will be presented.

2. Principle of chromatographic separation

In general, separation is a process in which a mixture is divided into at least two fractions of different composition. From a chemical point of view, the purpose of the substance separation process is to increase the concentration of one component of the initial mixture relative to the other components of the starting mixture. Separation is achieved through the use of physical methods as well as chemical reactions.

In 1903, in Warsaw, the Russian chemist Cwiet filled a glass tube with calcium carbonate (solid) and passed through it, or rather through a bed of calcium carbonate, a gasoline extract from leaves containing dissolved chlorophyll. Tswiet noticed that the chlorophyll had separated into three bands of different colors. Passing additional amounts of gasoline through the column caused the colored bands of chlorophyll to move down the column. By continuing to wash the column with gasoline, it was possible to successively wash out the individual bands (fractions) of chlorophyll from the column and collect them in separate vessels.

Based on the description given, it can be concluded that the chromatographic system consists of the following elements: stationary phase (in this case calcium carbonate), mobile phase (gasoline), – a mixture of separated substances. These elements are present in every chromatographic system. The condition that must be met for the separation process to take place is the movement of one phase relative to the other phase. In the experiment described above, the gasoline extract or gasoline was the mobile phase relative to the stationary phase, which was the packing of the column, i.e. calcium carbonate.

As a result of passing the mixture through the column, the components of the mixture were separated, so the individual chlorophyll fractions traveled at different speeds.

Chromatography is a physicochemical separation method in which the components to be separated are divided between two phases: one is stationary (stationary phase) and the other (mobile phase) moves in a specific direction. The different distribution of the components of the mixture between the two phases results in different migration rates and separation of the components.

The mobile phase moves inside the column while the stationary phase is deposited on the inner walls of the column. Chemical compounds with greater affinity for the stationary phase are selectively retained by it and move along the column much more slowly. On the other hand, chemical compounds with lower affinity to the stationary phase move faster along the column and thus leave the column, i.e. elute from the column first. The partition equilibrium between the phases is dynamic, i.e. the molecules of the substance constantly pass from the mobile phase to the stationary phase and back again.

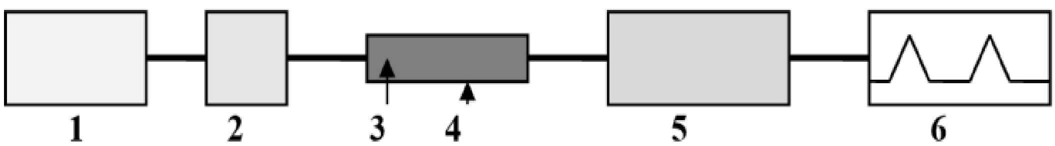

Figure 1. Block diagram of the chromatograph.
Source: own elaboration.

Figure 1 shows a block diagram of a liquid chromatography system. The stationary phase (3) is contained in a metal column (4) through which the mobile phase, usually pumped under high pressure by means of a pump (1), flows. The chromatographed mixture is introduced into the column (4) by means of a special dispenser (2). The mixture of substances separates in the column and the first migrating component enters the detector (5) the fastest. The detector is sensitive to a change in concentration in the mobile phase and when a substance appears in the detector (concentration change), it reacts with a change in electric voltage, which, after amplification, is recorded by a graphic recorder (6). The recorder records all changes in the concentration of successively appearing, separated substances in the column in the form of a series of peaks, which we call a chromatogram.

In column chromatography, the components of the mixture must pass through the entire column and only when they are in the detector can they be detected. In this way, a chromatogram is obtained, which can be treated as a dependence of the concentration of the substance on the duration of the analysis, or the volume of the mobile phase flowing through the column.

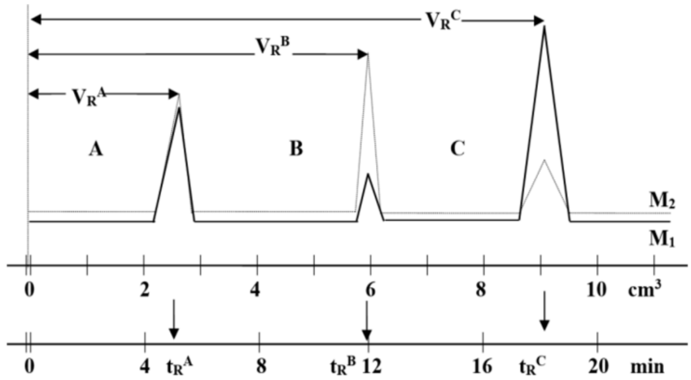

Figure 2. The process of creating a chromatogram.
Source: own elaboration.

In HPLC chromatography, the retention volume VR is an analogous quantity. The retention volume is the volume of the mobile phase that must flow through the column from the moment the substance is introduced into the system until the maximum of the peak appears in the detector. Yet another quantity that is used in HPLC is the so-called retention time tr, i.e. the time that elapsed from the moment of introducing the substance into the system until the maximum of the peak appears in the detector. In Figure 2, the arrows show the retention times for substances A, B and C.

3. Algorithm of chromatographic data separation

In this chapter of the presented work, the chromatographic data separation algorithm and the data classification algorithm will be presented, which will use chromatograms, i.e. data structures that are the result of the chromatographic separation algorithm.

The chromatographic data separation algorithm is based on the basic paradigm that the processed data string is a complex chemical molecule with a linear chain structure or a set of molecules with any number of molecules. This means that each data vector or set of vectors will be processed by the chromatographic algorithm according to the rules that apply in the real chromatographic system.

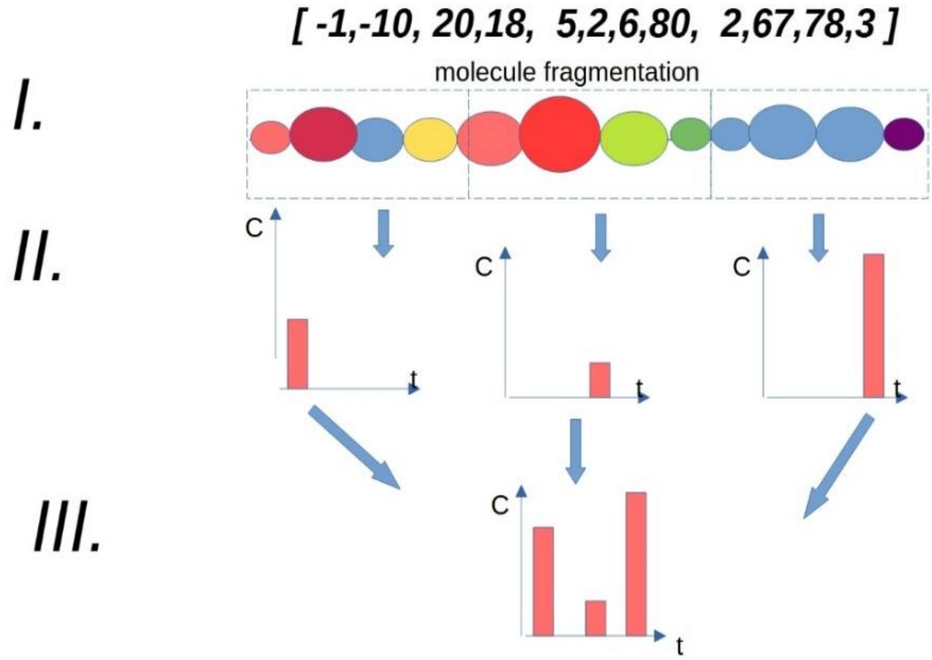

Figure 3. Operations of the chromatographic data classification algorithm.
Source: own elaboration.

The general principle of operation of the data chromatographic separation algorithm will be to clock a given data vector as a mixture of chemical compounds and for each "chemical" relationship between the concentration of a given substance in time – at the output of the chromatographic column, in other words, it will consist in calculating the spectrum, such as this is shown in the figure. In the first phase, we treat a sequence of numbers, a vector as a polyatomic molecule with a linear structure. In the next phase, the process of dividing the molecule into smaller molecules is carried out. In the third phase of the algorithm, each newly formed molecule is processed by a chromatographic column, i.e. the retention time is calculated. As a result of these operations, a chromatogram is created, i.e. a graph describing the concentration of a given type of molecules as a function of time at the output of the "chromatographic" column. This relationship, i.e. the chromatogram, is referred to as the spectrum of a given starting substance in the following part of the publication, and in this case it will correspond to the starting vector.

The chromatographic data separation algorithm consists of the following sequence of operations, which are inspired by the functioning of a real chromatographic system:

1) Mixing phase for a given vector
2) Retention Time Calculation Phase
3) Chromatogram creation phase
4) Spectrum analysis phase.

In the first phase of this algorithm, a set of vectors W consisting of any number of vectors, each of which is to be subjected to the classification process, is transformed into a set of mixtures of substances in such a way that for each element of the set W a mixture of substitutions is created which corresponds to this element of the set W.

Input data
$W=\{w_1,w_2,w_3....w_N\}$ – a set of data vectors that will be processed

Output data
$CH=\{ch_1, ch_2, ch_3....ch_N\}$ – a set of chromatograms, where each element of this set represents a chromatographic spectrum corresponding to a given element of the set W

$\boldsymbol{MS_{i..M}=[];}$
$\boldsymbol{W=\{w_1, w_2, ...w_M\}}$

Foreach w є W

For a given wi data vector, create a mixture of substances - it will fragment the vector into sub-vectors of constant length
$\boldsymbol{MS_i=\{s_1, s_2, ...s_{M(i)}\}}$

$\boldsymbol{MS_i}$ *-a set of substances is created by dividing a vector into sub-vectors according to the adopted principle of division,*

$\boldsymbol{ms_i}$ *- the elements of this set is the set of substances resulting from the division of the vector* $\boldsymbol{w_i}$ *,this means that the set will contain individual substances s which are not subject to further subdivision*
$\boldsymbol{ms_{M(i)}:=\{s_1, s_2, ...s_{M(i)}\}}$
a substance that was created by splitting the wi vector. $\boldsymbol{w_i}$.

Foreach s є $\boldsymbol{ms_i}$

Calculate Retention Timei t_r – the residence time of the substance in the stationary phase

end

end

As shown in the algorithm presented above, the set of mixtures of substances that has been created is fed to the input of the "virtual chromatographic column" in which the process of migration of a given substance between the stationary phase and the mobile phase takes place. The affinity to the stationary phase for a given substance depends on the retention time tr, i.e. on the residence time of the substance in the stationary phase.

For a given set of substances $\boldsymbol{MS_i}$ *,that have been processed by a chromatographic column, i.e. they have a calculated retention time* t_r

ch_i***=[];***

Foreach s є $\boldsymbol{MS_i}$

$\boldsymbol{peak_i[\ s.Tr\ ]:=peak_i[\ s.Tr\ ]+1}$

end

The next step of the presented algorithm is to create a chromatogram for a given mixture of substances that corresponds to the wi element. The chromatogram is created as a result of the registration of individual substances at the output of the chromatographic column. The moment at which a given substance will leave the chromatographic column will depend only on the retention time tr. The task of the detector is to count the molecules of the substance leaving the chromatographic column at a given moment of time.

The process of detecting a substance, which was created as a result of passing a substance through a chromatographic column of a mixture of substances corresponding to a given element of the input data vector w, was presented in the above-mentioned algorithm. The result of this algorithm is the chi chromatogram for the wi element.

Using the algorithms presented above, we can create a set of chromatograms of mixtures of known substances, which will correspond to a given vector from the set of input vectors.

The last stage of recognizing the substances that have been processed by the chromatographic system is the stage of classifying the output chromatographic spectrum and assigning it to known spectra.

Due to the structure of the spectrum – chromatogram, the recognition process in the case of real chromatograms is a complex process and so far eluding effective algorithmization. This is due to several factors. The first factor is impurities in mixtures of chemical substances that affect the final form of the chromatogram. Other factors, which are from the design of the detector that records the concentration of the substance at the output of the chromatographic column.

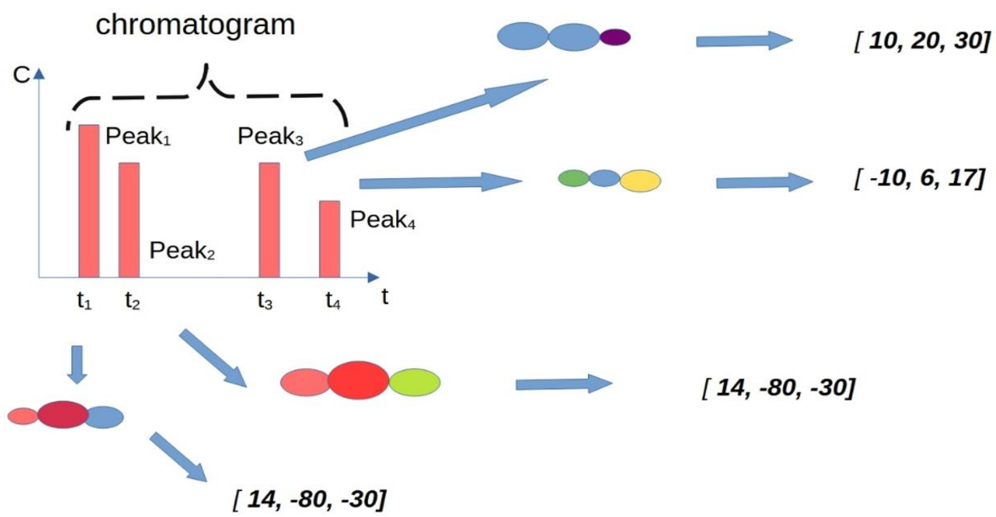

Figure 4. Structure of the chromatogram – the spectrum corresponding to the wi vector.
Source: own elaboration.

The chromatogram of the tested mixture of substances describes the concentration of individual compounds that are the composition of the tested substance and which have been separated as a result of the chromatography process, similarly in the case of the presented algorithm. As shown in the figure above, as a result of the chromatography process, we obtain a chromatogram that contains many peaks corresponding to the concentration of sub-vectors, which were created as a result of the operation of algorithm 1. The task of the classification algorithm will be to assign the chromatogram chx to the chromatogram or chromatograms of known vectors.

The input for this algorithm is the ch_x chromatogram, which will be compared with the elements of the set of CH chromatograms that correspond to each class. The second input of this algorithm is a set of CH chromatograms.

0 ***Input data***
$ch_a=\{peak_1,peak_2,peak_3....peak_N\}$ – a chromatogram consisting of N peaks
$CH=\{ch_1,ch_2,ch_3....ch_l\}$
$ch_i=\{peak_1,peak_2,peak_3....peak_M\}$ –a chromatogram consisting of M peaks

Output data
D - Distance a value that determines the level of similarity between the ch_a, and ch_b chromatograms
NoClass – class number

1 ***NoClass:=0; MinDist:=∞***
2 ***Foreach $ch_i \in CH$***
3 ***Foreach $peak^i_j \in ch_i$***
4 ***$P:=\{ peak^i_j \mid abs(t_r{}^i_j - t^x) < eps \}$***
5 ***$f_i:=f_i+sum(peak^i_j)$***
6 ***$f_x:=f_x+sum(P)$***
7 ***end***
8 ***$f_i:=f_i/sum(peak^i_j)$***
9 ***$f_x:=f_b/sum(peak^x_i)$***
10 ***$d_i:=sqrt((1-f_i)^2 + (1-f_x)^2)$***
11 ***$D:=D \cup d_i$***
12 ***end***
13 ***$NoClass:=\{i \mid min (D_{1..N}) = D_i \}$***

As follows from the presented algorithm, for each chi element belonging to the set of CH chromatograms, a match to the chx chromatogram is computed. The adjustment of the chx chromatogram to the chi chromatogram consists in finding all peaks belonging to the chx chromatogram, for which the difference between the retention time of the jth peak of the chi chromatogram is lower than the set value, i.e. from eps. For those peaks that meet the above criterion, two dw values are calculated (line 8), which is the sum of the peaks matched to the peak of the reference chromatogram. In line 9, the second value db is also calculated, which in turn informs how many peaks belonging to the chx-classified chromatogram have already been matched. In line 10, the match value is calculated between the number of matched peaks for the test chromatogram and the number of matched peaks in the reference chromatogram. As follows from the presented algorithm – the selected chromatogram, for which the formula defined in line 10, takes the minimum value, means that it will be a chromatogram for which the largest number of peaks belonging to the tested chromatogram was matched and at the same time the largest number of peaks were matched in the reference chromatogram. As follows from the presented algorithm, the only criterion for matching individual peaks is the peak retention time.

4. Presentation of the operation of the algorithm

In this chapter, the operation of the algorithm will be presented. The presentation of the algorithm will be carried out on an exemplary data set in which the dimension – the length of a single vector will have at least several hundred elements.

For the purposes of this article, an "artificial" data set was created according to the formula presented below in the form of pseudocode. As the presented algorithm shows, the training set consists of one hundred particles – vectors, and each of them belongs to a separate class. The number of classes and the number of vectors in the generated training dataset will be 100. However, the length of each vector – particle is 1885 elements.

```
aStep:=0.05
aEnd:=30
molecules:=[]
For i:=1 to 100
 A:=i
 f:=100/i
 molecules=molecules ∪{ A*cos( f*(0:aStep:aEnd*pi) ) }
end
```

The result of processing the training set by the algorithm will be the creation of a set of chromatograms, each chromatogram will correspond to one vector from the training set.

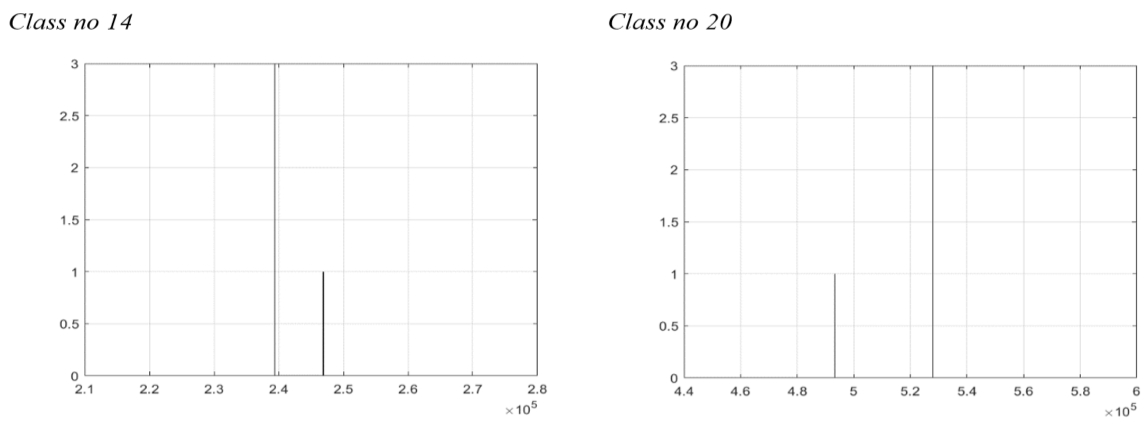

Figure 5. Chromatogram for class no. 14 and 20 for fragmentation level 200.
Source: own elaboration.

Figure 5 shows the chromatograms for two classes of the training set, which were created in the training process. On the horizontal axis of the presented graphs is the retention time, while on the vertical axis it is the concentration of molecules that were created in the process of fragmentation of the input vector. In this case, the fragmentation level was 200, which means that the vectors that were processed by the chromatograph were divided into molecules containing 200 elements each – according to algorithm 1. For each created molecule, the retention time tr was calculated and a chromatogram was created for each set of molecules in as described in Algorithm 2.

In a situation where the fragmentation will be a multi-stage fragmentation, the chromatograms will contain a proportionally greater number of peaks, thus the chromatograms will contain a larger number of peaks.

Class no 14 *Class no 20*

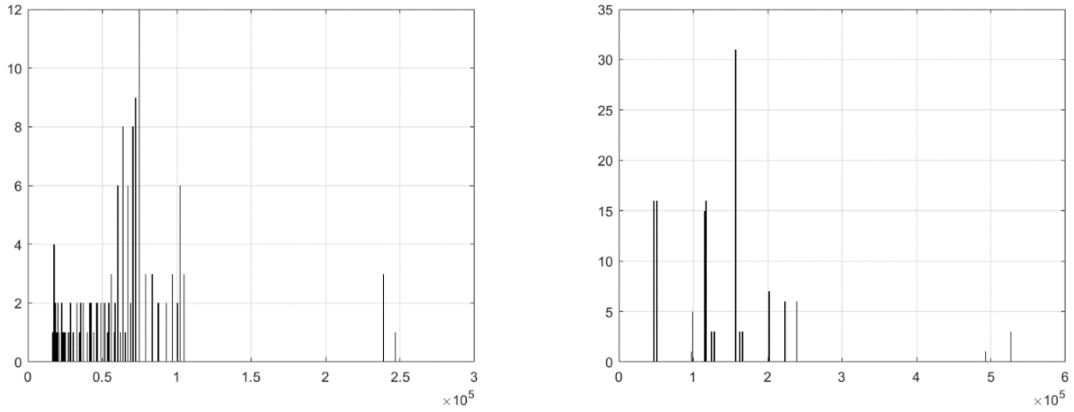

Figure 6. Chromatogram for class no. 14 and 20 for fragmentation level 20, 50, 200.
Source: own elaboration.

In a situation where the fragmentation will be a multi-stage fragmentation, the chromatograms will contain a proportionally greater number of peaks, thus the chromatograms will contain a larger number of peaks. Figure 6 shows the chromatogram of the same classes as before, but in this case the division was multiple, namely the input vector was divided into 20-element, 50-element and 200-element elements. You can see that new peaks have appeared in this case, but more importantly, the peaks that occurred with the single split have also been preserved.

Class no 14 *Class no 20*

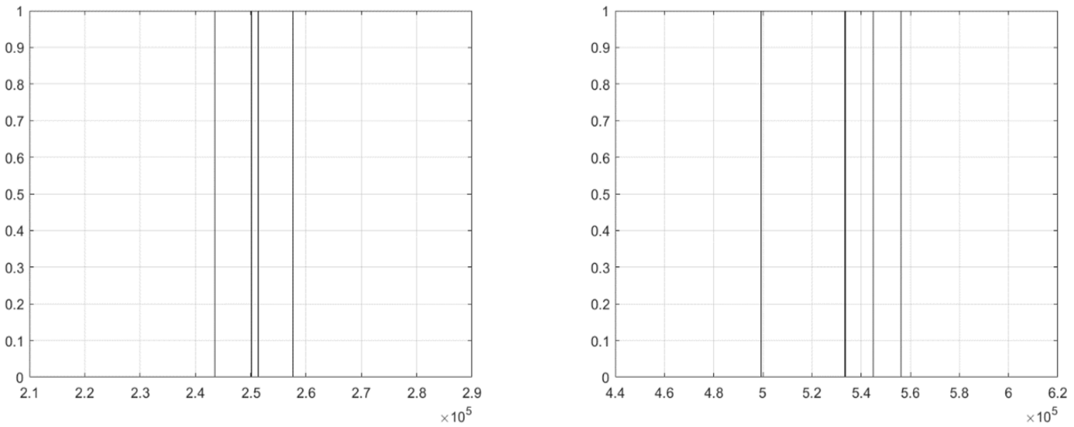

Figure 7. Chromatogram for class no. 14 and 20 for the level of fragmentation 200 with the level of distortion 50%.
Source: own elaboration.

The test set contained the same elements as the training set, but they were distorted, the level of distortion was 50%. Figure 7 shows the chromatograms of the test set for the same classes as before, but as mentioned, the data on the basis of which these chromatograms were created were subjected to the distortion process. As for such a high level of distortion, the peaks in the presented chromatograms either have the same value of retention time that occurred in the chromatograms in Figure 5, or they differ slightly from these values.

The classification process, i.e. the process of assigning an unknown chromatogram to a reference chromatogram, is carried out according to algorithm 3. In the discussed case, the classification process was successful.

Table 1 presents the results of classification using the chromatographic data separation algorithm. As can be seen from the presented data, the algorithm is relatively good at generalizing data, because at a relatively high level of distortion of the testing data. In the case of data distortions of fifty percent, the percentage of correct classifications reached the level of 77.50% of correct answers.

Table 1
The results of the classification by the chromatographic algorithm

No	The distortion level of the test data [%]	Fragmentation	Percentage of Correct Classifications[%]
1	50	50, 100	72.50
2	50	50, 100, 150	67.50
3	50	50, 100, 150, 200	72.50
4	50	20, 50, 100, 150, 200	77.50
5	25	50, 100	90.00
6	25	50, 100, 150	95.00

Source: own elaboration.

As the presented table also shows, the level of vector fragmentation has a significant impact on the level of correct answers. A higher level of vector fragmentation contributes to a few percent increase in the correct answers of the algorithm. The question arises whether the presented algorithm is actually better at data classification tasks than other commonly known algorithms, because no comparison of this algorithm with other data classification techniques has been included in this work. The reason for this is quite prosaic, the presented algorithm classifies vectors that have 1850 elements, which in the case of artificial neural networks it is practically impossible to classify vectors with such a large number of elements without reducing the vector dimension, e.g. using mathematical statistics methods.

At the end of the chapter on the presentation of the data separation chromatographic algorithm, two unique features of this algorithm should be mentioned. The first important feature is related to the fact that the vectors that are processed by the algorithm can be of different lengths. This is due to the fact that the input vectors used in the training process, i.e. creating a set of standard chromatograms, as well as vectors that are classified are divided into smaller fragments in the fragmentation process and it is from these fragments that a chromatogram is created.

The second property of the presented algorithm is the ability to classify data that includes data from several classes at the same time. For example, suppose we have a vector that contains data belonging to two classes, e.g. the data belongs to class 14 and class 20. Then the chromatogram of such a vector will look as shown in Figure 8.

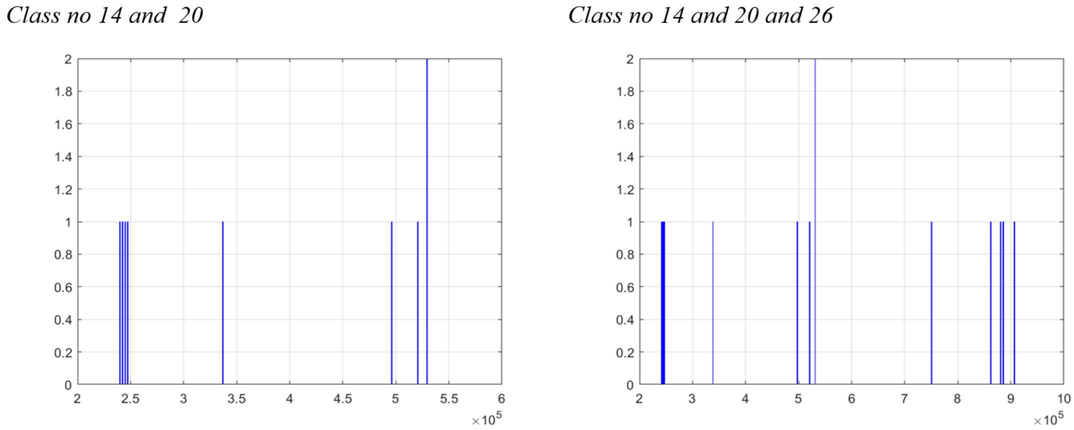

Figure 8. Chromatograms of vectors with a fragmentation level of 200 belonging to a) two classes: class 14 and class 20 b) to three classes: 14, 20, 26.
Source: own elaboration.

As can be seen from the presented figures, the chromatograms contain peaks that are appropriate for chromatograms belonging to class 14 as well as class 20. It follows that with the proposed data processing technique it is possible to classify cases in which the classified vector belongs to several classes at the same time.

5. Conclusions

This paper presents an algorithm for chromatographic data separation, which was inspired by one of the methods of analytical chemistry, which is separation chromatography. The article presents the proposed algorithms used in chromatographic data separation, such as the algorithm that transforms the processed data set into a set of chromatograms, the algorithm that classifies chromatograms. In the following parts of the article, the operation of the chromatographic data separation algorithm for the selected dataset was presented.

Due to the limited volume, the paper does not discuss the issues related to the optimal selection of the stationary phase, on which, among other things, the value of the retention time depends. It was also indicated in the work that this technique enables the classification of data vectors belonging to many classes of the so-called multi-spike vectors.

Based on the presented results, it can be assumed that the technique of chromatographic data separation can be successfully used in the processing of large data sets, where the data do not always have such features as a constant length of vectors, a relatively small number of elements in vectors, etc.

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