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CONTENTS

Editorial preface	5
Civil Engineering and Transport	9
1. BARCZAK ACESZKA Impact of the Covid-19 pandemic on rail freight transport in selected EU countries	11
2. IGNAC-NOWICKA JOLANTA Evaluation of static loads for manual warehouse work using computer simulation – case study	17
3. STOŁTNY BARTOSZ, PERUŃ GRZEGORZ, ŁAZARZ BOGUSŁAW, STOŁTNY ADAM The impact of teaching load on the safety of performing aviation tasks	25
4. PAWELSKI JAN Barriers impending introduction of autonomous vessels	34
5. HEJMLICH ANDRZEJ Impact of psychological components of human factors on the probability of committing an error during ship handling in restricted waters	42
6. RASZEJA MAGDALENA, HEJMLICH ANDRZEJ, NOWICKI JACEK, JAWORSKI TOMASZ Free running ship model tests of interaction between a moored ship and a passing ship	50
7. TABOR JOANNA Use of the grey incidence analysis in the inland waterway transport system assessment	57
8. MOUSAVI SEYED MOHAMADREZA, KHOOGAR AHMAD REZA, GHASSEMI HASSAN Ship nonlinear roll motion identification using artificial neural network	65
Material and Mechanical Engineering	75
9. WIATEREK DANIEL, CHYBOWSKI LESZEK Comparison of selected models useful in ranking the root causes of explosions in marine engine crankcases	77
10. PASTIEROVIČOVÁ LUCIA, KUCHARIKOVÁ LENKA, TILLOVÁ EVA, CHALUPOVÁ MÁRIA Iron impact on the quality of sand casting made from secondary AlSi7Mg0.6 alloy used in the automotive and aerospace industry	86
Environmental Engineering and Mining	93
11. SOKOŁA-SZEWIOLA VIOLETTA, PONIEWIERA MARIAN Verification of the deposit model and determining the course of the fault in the entire rock mass	95
12. MOCEK PIOTR, MOCEK KINGA Health effects of long-term exposure to industrial dust in preparation plants of hard coal mines	102
13. MIELIMĄKA RYSZARD, KLETA HENRYK Deformations of a dog heading located in an area of intensive mining operation – case study	113
14. KORBIEL TOMASZ, CZERWIŃSKA-LUBSZCZYK AGNIESZKA, BRODNY JAROSŁAW, CZERWIŃSKI STEFAN Economic aspects relating to machine operations on a mine main drainage system	122
Power Engineering	131
15. POPCZYK MARCIN Possibilities of recovery of fine-fraction energy waste from fluidized bed boilers in underground mining for liquidation of underground workings	133
Sustainability and Smart City	141
16. STEMPIŃSKI SZCZEPAN Hypothetical consequences of chemical contamination in the territory of the Municipality of the City of Szczecin during transport of hazardous materials	143

17. KAUF SABINA, PISZ IWONA	
Smart and valued? ICT urban (transport) solutions in the city official communication	152
18. BRUSKA ANNA, BOICHUK NATALIJA	
Is sustainable aligning with smartness in transport domain? – marketing perspective of smart city rankings	162
Economics, Management and Quality Science	173
19. SROKA MARIUSZ	
The impact of the human factor on the functioning of the quality management system in the enterprise	175
20. CIECIŃSKA BARBARA, OLEKSIK BEATA, FURTAK JULIA	
Hazard, risk assessment and safety management in workstations with lasers – theoretical and practical studies .	183
21. MARYNIAK ANNA, POGORZELEC-GLASER KATARZYNA	
The nature of the intercontinental supply chain and the building of its resilience in a company performing quality analyzes of engine oils	193
22. DEPCZYŃSKI RADOSŁAW	
Energy and labor intensity of manufacturing processes progressing toward sustainable development: A systematic literature review and SWOT analysis for a steel manufacturing company	201
Reviewers in 2022	211

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Editorial preface

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Dear Readers,

We are pleased to present you the last issue of our Scientific Journals of the Maritime University of Szczecin in this year. In this last edition, you will find twenty-two articles addressing topics from a wide variety of research areas. They have been grouped into the following sections: Civil Engineering and Transport, Material and Mechanical Engineering, Environmental Engineering and Mining, Power Engineering, Sustainability and Smart City, Economics, Management and Quality Science. We are pleased that the manuscripts submitted to us cover such a broad research field. This allows us to offer our readers a multi-disciplinary spectrum of research problems.

In the Civil Engineering and Transport section, we present eight studies. In the first study, the author addressed the impact of  Covid-19 on the transport industry. The research objective was to determine how the situation of rail freight transport in selected EU countries has evolved in the post-pandemic era. The trend of rail freight transportation in 2015–2021 and forecasts for 2020–2021 using the seasonality index method were presented. The second article analysed static loads on the human body during selected manual unloading activities performed by warehouse workers at a logistics company. A tool in the form of 3D SSPP ergonomic workload assessment software was used to conduct static load analyses. The values of the developed forces of the muscles working statically and the forces acting on the spinal vertebrae were determined for the two selected activities. For the identified values of static loads, based on the simulations of the 3D SSPP program, modifications of the working position and a change in the way of performing the tested activities were developed. The subject of the following study is flight training in the academic internship of aviation students. The problem of overloading the curriculum with theoretical subjects which negatively translates into practical training is shown. The research covered aircraft mechanics and aircraft crews. The author of another study notes that the shipping industry is currently experiencing a shortage of properly trained and competent deck and engine officers. He goes on to say that one solution is to replace manned vessels with autonomous units, however, the introduction of autonomous vessels faces barriers. The biggest problem lies in the international regulations, which have been prepared only for manned vessels, which means that there is an urgent need to change the existing legislative provisions. The next article presents a new approach to assessing the impact of the human factor on the risk of marine accidents based on a formal definition of the human-ship-environment system that takes into account the relationship between man, technology, the environment and the organization. The main objective of the research was to develop a method for assessing the impact of the human factor on the risk of a manoeuvring accident in restricted waters, based on studies of technical ship operation and using the results of the psychological profile of the operator. The research

was conducted with a group of 32 experienced ship captains performing a complex manoeuvring task on the Full Mission ship handling simulator. The authors of another article presented a study of hydrodynamic forces acting on a ship moored to a fixed quay, generated by other ships passing by using slow-moving ship models with much larger dimensions than those used in towing tanks. The goal was to determine the effect of force interaction on the manoeuvre. The research was conducted at the Ship Handling Research and Training Centre in Iława. The purpose of the next article was to point out the possibility of using Grey Incidence Analysis (GIA) to identify key factors related to the operation of the inland waterway transportation system. GIA is classified as a multi-criteria decision-making method and is one of the key applications of Grey Theory Systems (GTS), or systems with incomplete and uncertain information about structure and behaviour. The use of GIA to assess the inland navigation system is an original concept. In the last article in this section, the authors note that solving the nonlinear equation of rotation of a ship about its longitudinal axis, even under simplifying assumptions, is a complex problem. Calculation of the ship's roll reaction is possible by determining the coefficients of the roll equation. In the study presented here, the coefficients were determined from the dynamic response of the ship using a feed-forward learning neural network. The training was conducted in two modes: as a free swing in calm water and a forced oscillation in irregular waves. The DTMB 5415 vessel was used in the experiment.

In the Material and Mechanical Engineering Section, we have two manuscripts. The first article compares three different models taken from the literature describing the causes of explosions in the crankcases of marine engines. In all cases, the same process was analysed, i.e., explosions in crankcases. A statistical assessment of the frequency of events leading to explosions, a model built using Failure Modes and Effect Analysis (FMEA) and a model based on Fault Tree Analysis (FTA) were presented. Valid measures of all fault tree elementary events were calculated using the Birnbaum reliability measure, the Vesely-Fusel measure, the Birnbaum structural measure, the criticality measure and the improvement potential. The percentages of importance of all events determined by these measures of importance were compared. The results of the models were compared with each other and an approach using all three models supplemented by deviation analysis was proposed. The second article examines the effect of elevated iron content on the quality of AlSi7Mg0.6 sand castings. Since these materials are mainly used to produce castings for the automotive industry, such as engine blocks, cylinder heads, etc., it is necessary to produce castings without defects. Therefore, the quality of AlSi7Mg0.6 sand castings is tested at a lower iron content (0.128 wt. % Fe) and compared to a higher iron content (0.429 wt. % Fe), while the correlation between iron content and porosity is monitored.

In the Environmental Engineering and Mining section, we present four articles. The first article presents the results of work on developing new methods for introducing discontinuity lines into the numerical model of a deposit in CAD systems. As the authors note, the main problem in creating a numerical model of the deposit is usually the very small number, as well as the low reliability of the source data. This provided the rationale for the authors to develop new algorithms for the introduction of discontinuities, which can be used in conditions where there are a large number of discontinuities. As a result of this research, the paper presents algorithms for introducing discontinuities into the entire deposit model. The method of transferring faults from the higher seam to subsequent seams and determining the course of the fault throughout the rock mass is described. The authors of another study note that statistics on occupational diseases recorded by the Institute of Occupational Medicine in Lodz indicate a renewed increase in cases of pneumoconiosis in Poland in recent years, especially in the PKD section – mining. Therefore, an attempt was made to assess the dust hazard and the incidence of respiratory diseases among workers at the X mine tailings plant exposed to harmful industrial dust generated in the work process. The results made it possible to identify the workplaces most exposed to the harmful effects of industrial dust and to recognize the effects of this action in the form of pathological changes in the respiratory system in 18.4% of the miners surveyed. The third article of this section presents the results of a study of the extent of the impact of mining operations in the rock mass at the site of mine workings located in an area of intensive mining operations. The research is based on the results of geodetic measurements of the settlement of survey line points located above the panel of the depleted wall. The study was used to assess the extent of the impact of rock mass exploitation in the rock mass, which is important for protecting mine workings from mining damage. The last article of this section presents an economic analysis of the operation of the main mine drainage depending on the condition of the machinery. The analysis was based on actual operating data obtained during the operation of an underground coal mine. Through the selection of state estimators, appropriate sensory systems, and a long-term economic approach,

operating procedures have been developed that have introduced significant financial savings. The article also addresses an area related to water safety and pumping station reliability.

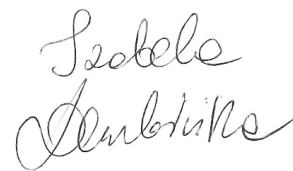
In the Power Engineering and Mining section, we present one article. The author writes that the Polish energy industry is based mainly on solid fuels such as hard coal and lignite, and there is a problem with managing significant amounts of combustion waste. The author notes that one of the directions of recovery of this type of waste is underground coal mining, where the general problem of their management is the variability of physical and chemical properties resulting from the combustion of fuels with different parameters in power boilers with different flue gas and solution treatment, mainly the desulfurization method. One of the energy production solutions in use today is the combustion of coal in fluidized bed boilers, where the so-called dry desulfurization method is used, resulting in the production of a fine fractional waste with the European code 10 01 82, which is characterized by pozzolanic properties that allow its use wherever specific strength parameters are expected from the material. One such technology is the decommissioning of underground workings by pouring hydro-mix into the fenced-off space of the workings via a gravity-fed pipeline. The paper presents the results of laboratory tests of the physical and mechanical properties of hydro mixes made on the basis of selected fluidized bed boiler energy wastes, along with a practical example of their application to the decommissioning of underground workings.

In the Sustainability and Smart City section, we present three articles. The first article presents a hypothetical model of the spread of hazardous substances released during a crash involving a tanker truck carrying 20,000 kg of anhydrous ammonia by road, rail and water in the Szczecin Municipality. A 2016 train crash involving two derailed tank cars carrying ammonia was the research inspiration, and is evidence of the likelihood of such an event. The Chemical, Biological and Radiological Contamination Situation Assessment Method (ATP 45 (Delta)) and the Promień information system are used to forecast hypothetical contamination development. The results were compared with findings made using the ALOHA program. The main purpose of the following study was to determine the importance of Information and Communication Technologies (ICT) in the process of creating smart mobility in a smart city, based on texts posted on official websites. Using natural language processing (NLP) methods and tools offered by the CLARIN.EU infrastructure, the dominant connotations of mobility in cities considered smart were verified. The sample of cities is an excerpt from existing smart city rankings. The results of the study show that mobility is a distinct topic in smart city communications, encompassing different types of transportation solutions and systems, with a strong emphasis on the design side of this activity. The smart city theme is continued in the following study. The main purpose of the research was to see if there is a relationship between aspects of smartness and transportation sustainability in smart city rankings, and if so, what impact it has on the marketing communications of the city included in such rankings.

In the Economics, Management and Quality Science section, we present four articles. The first article attempts to analyse the degree of involvement of rank-and-file employees in the operation of the company's quality management system. The author analysed the expectations of the board of directors and executives in relation to the expectations and concerns of the company's rank-and-file employees. The research aims to diagnose the quality of information flow in the company based on the quality management system as assessed by the two groups surveyed, to determine the perception of the importance and scale of participation in the proposed corrective actions among the surveyed groups of respondents, and to diagnose the level of information provided to rank-and-file employees about the goals and importance of conducting internal and external audits. The following article presents the problems of using workstations with laser equipment, taking into account the nature of laser work and the specific effects of the laser beam on the material. The subjects of the analysis are a stand with a CO₂ laser for cutting polymers and a stand with a fibre laser for marking and engraving. The assessed risks at selected laser workplaces indicate that special attention should be paid not only to the devices themselves and the negative effects of their laser beams on the human body, but also to the materials being processed. The purpose of the third paper in this section was to identify a model for building a resilient supply chain in an engine oil sample testing company. The study found that at the level of the described chain, its strength and continuity of flow are based on the sustainability of supplier relationships, speed, trust and information exchange, the role of which was explained in connection with the nature of the supply chain. Due to the nature of the chain, building its resilience based on agility is not justified in this case. In addition, it was found that in this process, 4.0 technologies such as IoT, machine learning, artificial intelligence, and cloud technologies are more relevant to management at the whole corporation

level than at the level of the chain under study. The last study performed a systematic literature review and assessment of the energy and labour intensity of manufacturing processes in an industrial enterprise while proposing changes toward sustainability. The subject of the study was an industrial enterprise representing the steel production sector in Poland. In the literature survey, 163 scientific publications were downloaded from the Web of Science database. In terms of assessing the energy and labour intensity of manufacturing processes, twelve manufacturing processes were selected and then grouped according to the most important areas of similarity, i.e., automation, ergonomics and discomfort.

I hope that the presented studies will meet with wide interest, and at the same time inspire various interdisciplinary thoughts, discussions and research.



dr hab. Izabela Dembińska, Associate Professor
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Szczecin, 31.12.2022

Civil Engineering and Transport

Impact of the Covid-19 pandemic on rail freight transport in selected EU countries

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Keywords: European Union, pandemic covid-19, freight transport, rail transport, seasonality index method

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Abstract

The Covid-19 pandemic has affected all aspects of human life. Its negative effects have also hit the transport industry, largely as a result of staff contracting the virus and the restrictions imposed on human mobility. Therefore, the purpose of this study is to establish how the situation of rail freight transport in select EU countries has evolved in the post-pandemic era. The trend of rail freight transport is presented for the years 2015–2021, and forecasts are made for the years 2020–2021 using the method of seasonality indices. The study results show that most of the investigated countries show adverse differences in the actual and forecast quantity of freight handled, an effect clearly attributable to the pandemic.

Introduction

The Covid-19 pandemic has had a negative impact on all areas of social and economic life worldwide (Fang, Wang & Yang, 2020; Arena & Aprea, 2021; Barczak, 2021; De Vet et al., 2021; Xuan et al., 2021). It has also taken its toll on transport (Barczak, 2021; Tianming et al., 2021). The lifting of part, or all, of the restrictions has not led to a recovery to pre-pandemic levels (Kolakowski et al., 2021; Barczak, 2021). On the contrary, many lines of transport are facing significantly reduced transport demand (Bagdasarian & Ipek, 2022).

The impact of the Covid-19 pandemic on rail transport is indisputable. It has previously been investigated by a number of researchers and applies to different geographical locations and economic systems. For example, the impact of the pandemic on China's transport sectors has been researched in terms of demand and supply, which revealed heterogeneity in the impact of Covid-19 on individual

sectors. However, rail freight transport, rather than passenger transport, has been found to be less vulnerable to the negative impact of the pandemic (Cui et al., 2021). The literature also outlines the required steps needed for the rail sector to compete with other lines of transport in the event of future pandemic-like crises (Tardivo, Zanuy & Martín, 2021). The potential of the rail-road freight transport system has also been analyzed in international terms. Its potential to allow for new container-handling technological solutions has already been addressed. The authors argue that extending this solution to EU countries could result in a significant increase in the share of rail freight. Concurrently, the negative impact of the pandemic on supply chains would be mitigated (Vida, Illés & Bányainé Tóth, 2021).

From the brief literature review above, we can conclude that the Covid-19 pandemic has had a negative impact on rail transport worldwide. This is partly attributable to the rail freight transport being restricted in the early days of the pandemic due to,

in part, the challenges of inter-border shipments. Many countries would take case-by-case decisions to halt or severely restrict international traffic. However, after a few months, the international rail transport market situation improved, and transport volumes started to gradually increase. In Poland, as a result of the decrease in passenger services, the capacity of railway lines increased, positively influencing journey times and on-time performance of goods trains. With a high degree of confidence, we can presume that the situation was comparable in other countries.

The improved condition of rail freight transport operations has also been influenced by freight transport not having been subject to the same restrictions as passenger transport; some countries have even seen increases in traffic (e.g., Germany). National governments made it a priority to ensure continued freight exchange in the era of the pandemic in Europe. Alongside road transport, rail transport ensured the continuity of the supply of food and essentials and supported government efforts to deliver the tools to fight the pandemic, such as cleaning products, personal hygiene, and medicines and equipment (UTK, 2021). Concurrently, in a situation of restrictions on road freight, when trucks stood for hours at the borders, there was interest in rail transport for those goods that had not previously been transported by rail in Europe (Walków, 2020).

Notably, the (mainly financial) consequences, however, have been and continue to be paid by rail infrastructure managers and owners of service infrastructure centered around passenger rail transport. The COVID-19 outbreak has brought about a sharp drop in demand for rail transport services. This has had a serious impact on railway undertakings. The impact started to manifest itself as early as 1 March 2020, and it is likely to last until at least 31 December 2020. The circumstances linked to the COVID-19 outbreak are beyond the control of railway undertakings, which are facing considerable liquidity problems and major losses and in some cases the risk of insolvency (Regulation, 2020).

In view of the above, the purpose of this study is to investigate how the rail freight situation in select EU countries has evolved post-pandemic. However, the study excluded a distinction between national and international transport. Furthermore, freight volume forecasts for the period 2020–2021 were constructed on the basis of quarterly Eurostat data for the period 2015–2021, which are used to determine the scale of deviations that impacted rail freight traffic as a result of the Covid-19 pandemic.

Sample and methodology

The countries with the highest volume of freight transported by rail in 2019, i.e., countries with volumes exceeding 364,120 thousand tons, were selected for analysis (Figure 1). This group included Germany (364,120 thousand tons), Poland (233,744 thousand tons), Austria (102,575 thousand tons), the Czech Republic (98,804 thousand tons), and Italy (94,295 thousand tons).

With data for the years 2015–2019, we made forecasts of transported freight volumes in each quarter of 2020 and 2021 for the selected countries. As rail freight traffic in all analyzed countries is characteristic of additive seasonality, the method of seasonality indices was used to make forecasts. This method is generally well-known and widely reported in the literature (e.g., Sobczyk, 2006, pp. 231–232; Barczak et al., 2022). Therefore, the paper focuses on the result analysis without providing a detailed description of the method. Of note, however, due to the forecasting method not being based on a formal model, it is not possible to determine the forecast error (Jóźwiak & Podgórski, 2009, pp. 441–442).

Results

The portrayal of changes in the volume of transported freight (Figure 2) suggests a plausible hypothesis that the Covid-19 pandemic had a temporary negative impact on this line of transport. In Germany, 5.99% less freight was transported in 2020 but there has been 4.99% more in 2021 vs. 2019. Compared to 2019, it was 6.71% and 2.83% less freight in Poland, 4.94% and 0.73% less in Austria, and 7.63% and 1.31% less in the Czech Republic. In Italy, compared to 2019, there was a decrease of 5.68% in freight volumes in 2020 and an increase of 4.58% in 2021.

The following presents the results of the forecasts. For cargo in each of the countries analyzed, empirical data charts with a quarterly breakdown were created. On this basis, it was possible to make conclusions about the course of seasonal fluctuations. For all countries, the analysis showed that these are series with periodic fluctuations. The real-world data show a development trend with seasonality; therefore, the trend functions for each country were estimated (Table 1). The parameters of all the models set out in the Table are statistically significant at $\alpha = 0.05$.

Based on the above seasonality indices, Table 2 presents the freight traffic forecasts for the individual

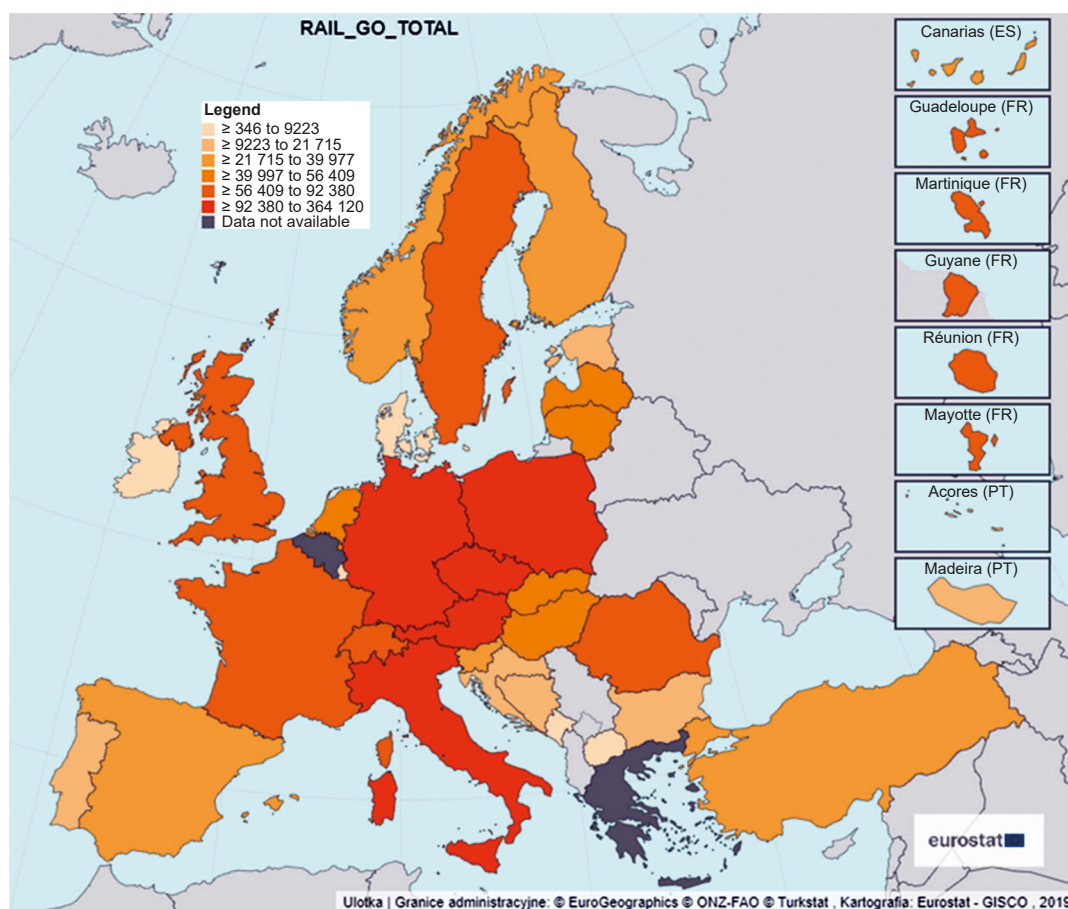


Figure 1. The volume of freight transported by rail in EU countries, 2019

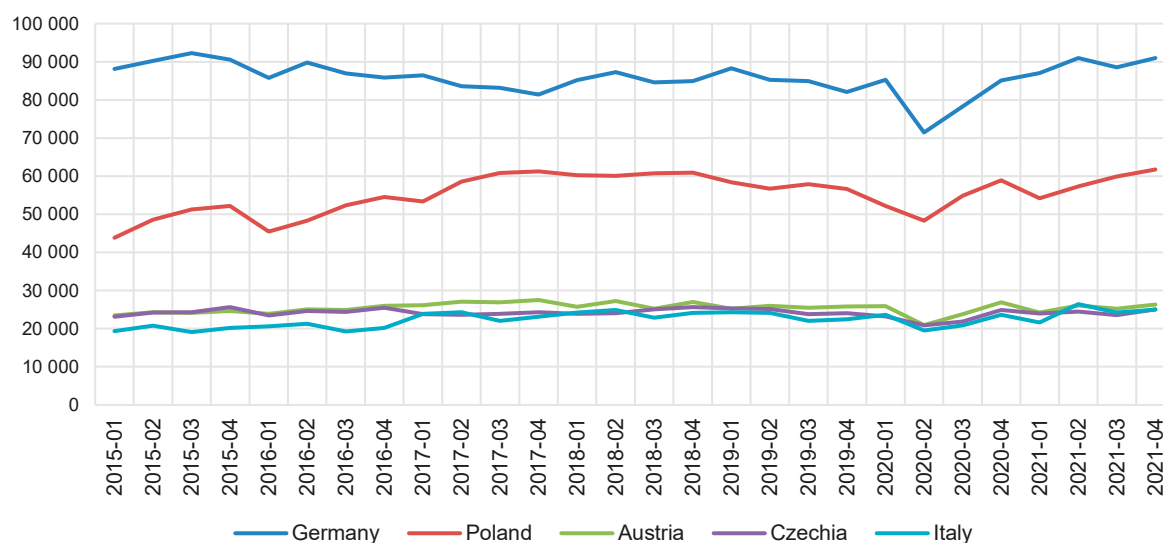


Figure 2. The volume of freight transported by rail in selected EU countries by quarter, data for 2015 to 2021

Table 1. Estimated functions of trends

Country	Trend function
Germany	$y_t = -309.9459 t + 89590.5316$
Poland	$y_t = 718.4481 t + 47561.1947$
Austria	$y_t = 118.2218 t + 24344.7211$
Czechia	$y_t = 28.5429 t + 24092.9000$
Italy	$y_t = 239.5496 t + 19637.1789$

quarters of 2020 and 2021. The forecast results are rounded to whole numbers.

Figures 3 to 7 show a comparison of the volumes of freight actually transported against the forecast values. The red line indicates the differences between the forecast values and the actual freight volumes in each country.

Table 2. Forecasts for individual quarters of the years 2020 and 2021

Country	Forecasts 2020			
	Quarter I	Quarter II	Quarter III	Quarter IV
Germany	83 043	83 497	82 666	81 245
Poland	60 896	63 037	65 237	65 720
Austria	26 321	27 346	26 744	27 607
Czechia	24 271	24 685	24 612	25 357
Italy	25 337	25 947	23 931	24 878

Country	Forecasts 2021			
	Quarter I	Quarter II	Quarter III	Quarter IV
Germany	81 802	82 257	81 426	80 005
Poland	63 769	65 911	68 110	68 594
Austria	26 794	27 819	27 217	28 080
Czechia	24 385	24 799	24 726	25 471
Italy	26 295	26 905	24 889	25 836

In Germany, in the first and fourth quarters of 2020, the actual freight volumes exceeded the forecast by 2258 thousand tons and 3831 thousand tons, respectively. Throughout 2021, the forecast volumes are lower than the actual freight volumes. The

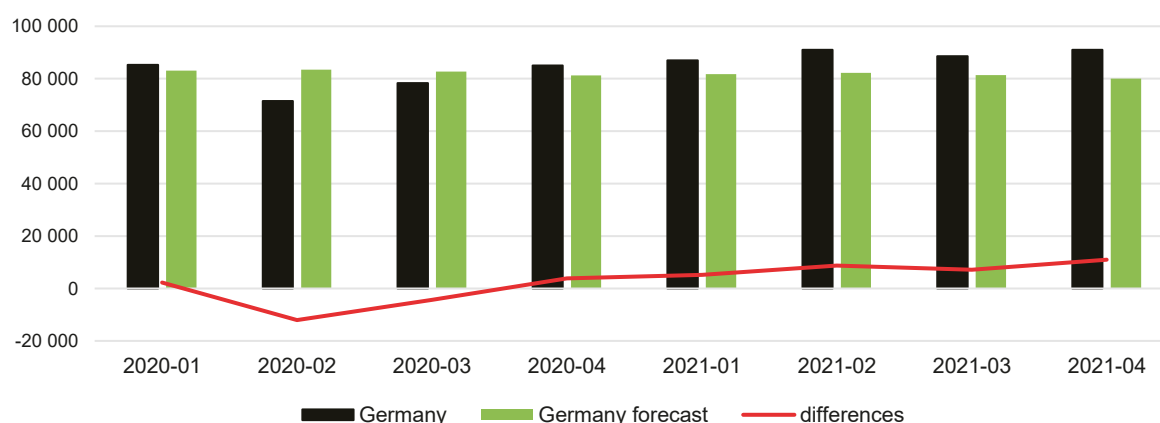
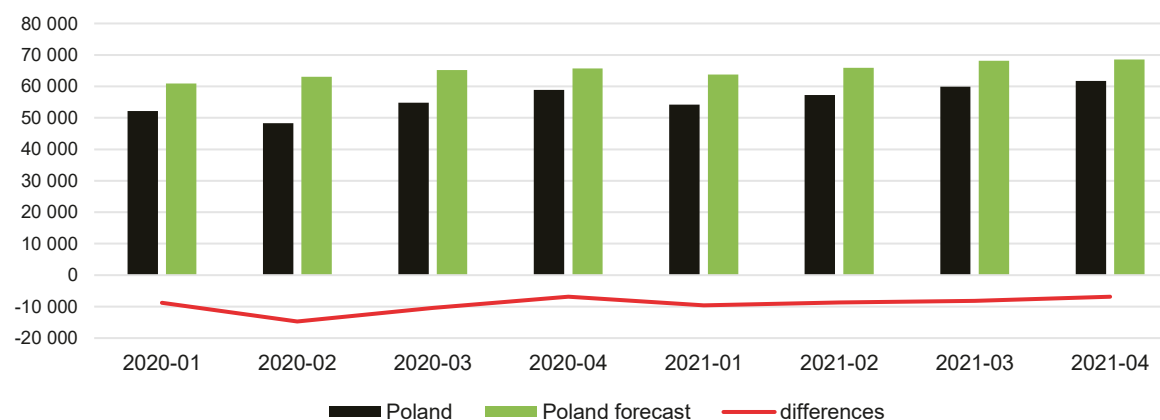
differences are as follows: 5223 thousand tons, 8755 thousand tons, 7124 thousand tons, and 10,971 thousand tons (Figure 3).

In Poland, all the actual values were lower than forecast. The largest differences were recorded in the second and third quarters of 2020, i.e., 14,718 thousand tons and 10,371 thousand tons, respectively (Figure 4).

As in other countries, the volume of transported freight in the second and third quarters of 2020 decreased significantly in Austria. Compared to the forecast values, these were decreases of 6412 thousand tons and 2972 thousand tons, respectively. In the other periods, the volumes of transported freight were slightly lower than forecast (Figure 5).

For Czech rail freight transport, all volumes in 2020–2021 fall short of the forecast volumes. The highest differences were reported in the second and third quarters of 2020: 3816 thousand tons and 2716 thousand tons, respectively (Figure 6).

In Italy, the volumes of transported freight decreased significantly in the second and third quarters of 2020. Compared to the forecasts, these were decreases of 6396 thousand tons and 3042 thousand

**Figure 3. Comparison of actual and forecast freight volumes in Germany****Figure 4. Comparison of actual and forecast freight volumes in Poland in the Czech Republic**

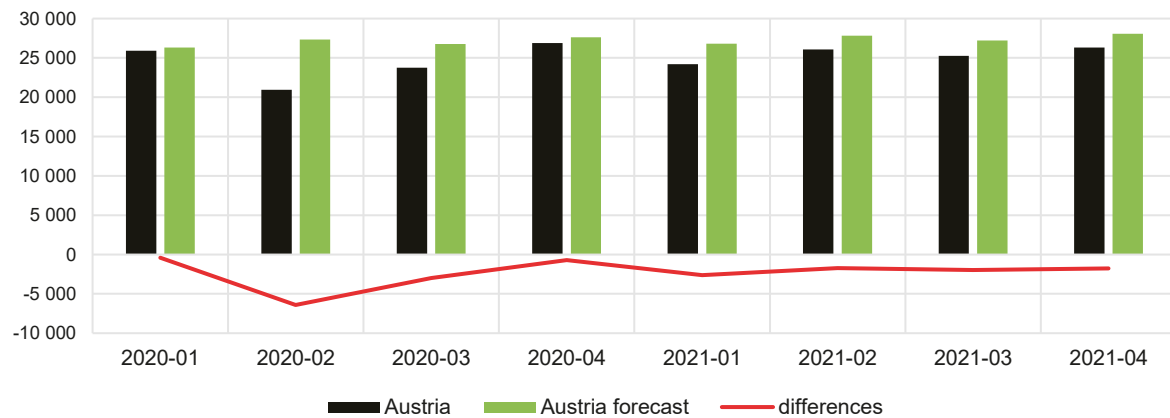


Figure 5. Comparison of actual and forecast freight volumes in Austria

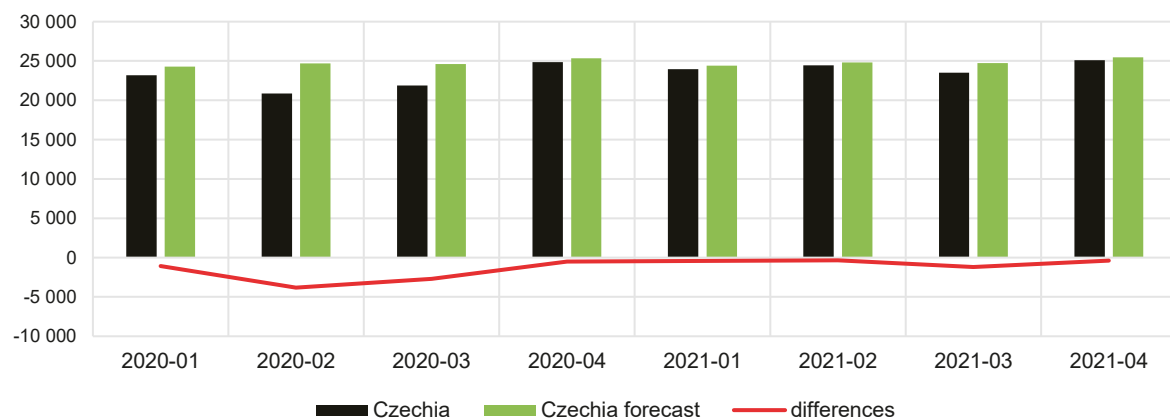


Figure 6. Comparison of actual and forecast volumes in the Czech Republic

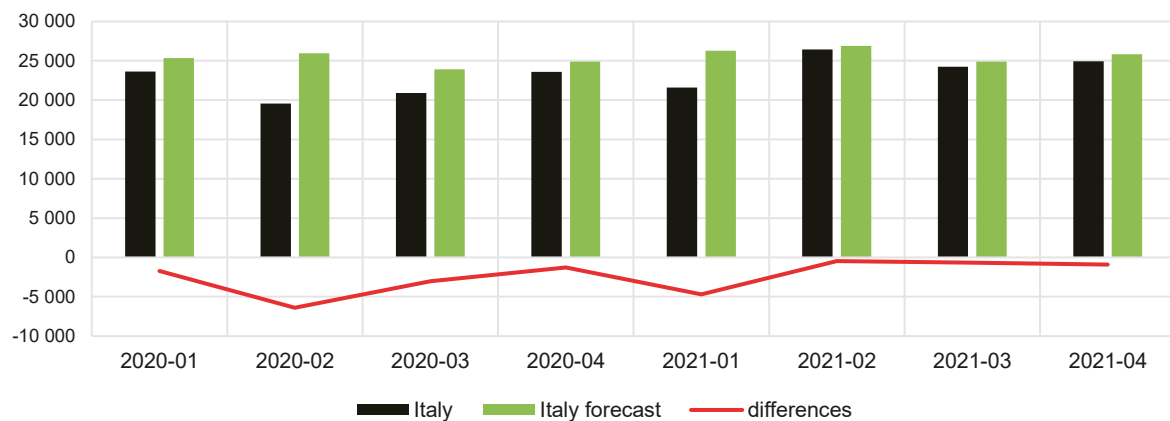


Figure 7. Comparison of actual and forecast freight volumes in Italy

tons, respectively. A major decrease, against the forecast values, was also recorded in the first quarter of 2021, at a value of 4696 thousand tons. Notably, all the actual freight volumes were lower than the forecast values (Figure 7).

Conclusions

As the rail freight and passenger transport restrictions had a different “impact zone”, it is reasonable

to expect that rail freight volumes will recover after the initial shock due to the declaration of the state of pandemic threat. All the countries under review reported significant declines in freight volumes in the second and third quarters of 2020. However:

- In Germany, after the aforesaid decrease, there has been a significant increase exceeding the pre-pandemic level of transport. Compared to the estimated forecasts, it is reasonable to estimate that between 2020 and 2021 there was a surplus

of 21,764 thousand tons of freight transported in Germany;

- In Poland, after the initial decline, transport volumes have been higher than in the previous years, but lower than forecast. It is, therefore, reasonable to estimate that Poland's 2020–2021 volume of transported freight fell 73,931 thousand tons short of the forecasts;
- In Austria, after two quarters of decline, the volume of transported freight evolved at a similar level as in the pre-pandemic period. However, the freight volumes were 18,591 thousand tons lower between 2020 and 2021, as compared to the forecasts;
- In the Czech Republic, after the aforesaid decrease, the freight volumes took on a profile similar to that of the pre-pandemic era. However, they were lower than forecast. Between 2020 and 2021, the difference stood at 10,455 thousand tons;
- In Italy, as in the other countries, the freight volumes started to gradually rebound to the pre-pandemic level following the reported decreases. Between 2020 and 2021, the actual freight volumes were lower than forecast. During the reference period, the difference stood at 19,151 thousand tons.

Although freight traffic has been diverted to rail, as far as possible, due to international traffic restrictions and travel requirements for truck drivers in some countries (e.g., Germany), the rate of growth in freight volumes has slightly slowed versus the previous years. Our findings clearly point to the major differences between the volume of transported freight and the forecast values. In view of their readings, the select countries only saw a fall of 133,437 thousand tons of freight transported by rail.

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Evaluation of static loads for manual warehouse work using computer simulation – case study

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JEL Classification: J81, J82, L91, R41

Abstract

This article presents an analysis of the static loads on the human body during selected manual unloading tasks carried out by warehouse workers in a logistics company. The aim of the presented analyses is to minimize static loads in the work process and thus make the employees' work more comfortable. A tool in the form of 3D SSPP software for ergonomic workload assessment was used to carry out static load analyses. For the two selected activities, the values of the developed forces of statically working muscles and the forces acting on the vertebrae of the spine were determined. For the values of static loads identified, based on the simulation of the 3D SSPP program, modifications in work posture and a change in the manner of performing the tested activities were devised. Moreover, the proposed reorganization of the tasks examined was verified by the reassessment of the static loads on the muscles using the 3D SSPP tool. The analyses carried out after the reorganization of work confirmed the reduction in static loads and the improvement in work comfort for the analyzed manual tasks.

Introduction

Advances in mechanization and the automation of production processes have resulted in the spread of monotypic movement work, most often involving a high load on the muscles of the fingers, hands, and forearms. Performing this type of motor operations is usually associated with forced positions of the body and resulting postural stress (Gembalska-Kwiecień & Ignac-Nowicka, 2014; Janiga, 2014).

Data from the European Union countries indicate the great importance of loads on the body, with a large proportion of time spent working in static positions under contemporary working conditions. The data show that over 30% of workplaces in these countries are associated with difficult body positions, over 40% with highly repetitive hand movements,

and nearly 20% with the need to move loads. This assessment is based on the assumption that a given type of load lasts for at least half the working time (Janiga, 2014). The described types of load contribute to fatigue and a decrease in a worker's exercise capacity, as well as various irregularities in the functioning of the musculoskeletal system (Tanaka et al., 2014; Galar & Kumar, 2016; Teymourian, Seneviratne, & Galar, 2019). Local overload can lead to degenerative changes that lead to pain in the muscles and spine. They most often occur in the dorsal part of the torso, including the neck and shoulders, and the lumbosacral region. An important element of the associated pain syndromes are changes resulting from overloads and microtraumas of the vertebrae and inter-vertebral cartilage (Gembalska-Kwiecień & Ignac-Nowicka, 2014; Janiga, 2014).

Static-type effort is a very important component of the overall workload. It consists in performing work when no limb or torso movement is observed, and the muscles remain tense and can counteract the force of gravity, e.g., holding a tool in a raised hand.

Static effort does not have a proportional rate of oxygen consumption and energy expenditure in relation to its severity, but it causes:

- severe fatigue;
- impairment of purposeful movements;
- negative impact on organs and systems responsible for the balance of the body;
- inhibition of the nerve centers that regulate circulation, respiration, and other activities (Konarska, Liu & Kurkus-Rozowska, 2002; Ignac-Nowicka, 2017).

An important feature of static operation is low energy consumption. Despite the low energy demand, the conditions for the formation of an oxygen debt and an increase in the importance of anaerobic changes are created in a statically working muscle. This results in the previously mentioned consequences, such as a feeling of discomfort and muscle weakness corresponding to fatigue (Ignac-Nowicka & Gembalska-Kwiecień, 2008; Ignac-Nowicka, 2012; Janiga, 2014). Under such conditions, workloads result in disturbances to the smooth performance of an employee's task. This may disrupt the production process in which the employee participates (Bernard et al., 2017; Teymourian, Seneviratne & Galar, 2017). Many such situations can be observed in warehouses, where manual unloading is dominant (Kabiesz & Bartnicka, 2018). Observation of warehouses and analysis of the discomfort reported by employees prompted the author to carry out a broader and detailed analysis of unloading tasks performed manually in order to optimize them and increase the comfort of performing selected tasks. Many cases of back and limb pain during manual unloading were reported in the analyzed enterprise. As the assessment of work or task ergonomics leads through the phases of prediction, recognition, and evaluation to corrective action, the static loads occurring during work (Stack, Ostrom, & Wilhelmsen, 2016) were analyzed, and a research tool was selected (Winkler, 2005; Ben-Daya, Kumar, & Murthy, 2016; Teymourian et al., 2021; University of Michigan software, 2022).

The problem of unnecessary static loads while performing tasks, especially physical ones, raised in this article, is a multilayered issue, affecting not only employees' health, but also work efficiency and company costs, which are concerns of employers.

A company's losses can be twofold, not only caused by lowered work performance, but also long-term because of the health issues of qualified staff. With the use of a static loads simulating tool, effective measurement possibilities for the optimization of work procedures can be implemented. Such solutions can enhance both work performance and comfort by lowering static loads, as will be presented.

The research tool used

The methodology of technical design, and in particular computer-aided design, is aimed at achieving the best technical parameters to achieve the desired object. This often leads to solutions in which the relationship between workers and the equipment employed is disturbed. The use of computer aided design has become common, where the design features of the created technology are written as three-dimensional geometric models. The forms of notation used make computer simulations closer to real objects to an increasing extent. The equipment employed together with the people for whom it is intended create, in turn, increasingly complex anthropotechnical systems. Due to the use of models of both technological objects and human anthropometric features, it has become possible to create a virtual human environment in which the relationships connecting people with their work environment are mapped (Winkler, 2005; Plinta, 2010; Zywert & Czernecka, 2011; Gembalska-Kwiecień, 2018).

The spatial models of the equipment employed are created with the methods of geometric modeling available in many design applications. These models fill the virtual workspace. Human presence in the work environment is considered by modeling the anthropometric features of the human body (Galar & Kumar, 2016; Bernard et al., 2018). Currently, biomechanical models are used to determine and analyze the load states of the musculoskeletal system (Maurice et al., 2019; Kabiesz & Bartnicka, 2020). They are used to assess the loads caused by:

- the weight of body segments;
- loads lifted or shifted;
- human forces during technical operations (Plinta, 2010; Zywert & Czernecka, 2011).

A dummy biomechanical model is particularly useful in the process of studying the effects of negative interactions in the anthropotechnic system. These models were based on the principle of operation of the ergonomic design tool – 3DSSPP version 7.0.6. This program is a graphical representation of

kinematic chains, with a particular emphasis on the analysis of static loads in the human musculoskeletal system (Teymourian et al., 2021; University of Michigan software, 2022). The 3D SSPP software was provided by the University of Michigan Office of Technology Transfer. It enables the simulation of work in a three-dimensional space, which includes data on posture, strength parameters, and male/female anthropometry (Maurice et al., 2019; Gomes et al., 2021; Vianello et al., 2022). The body position is selected by determining the values of the joint angles and the distance from the ground, or by shifting the anthropometric points of the manikin. The analyst can study the twists and bends of the torso and make entries about the strength of the hand. The analysis is supported by the automatic posture generation function and three-dimensional human graphic illustrations. In this way, the positions taken during the work are modeled, and the forces acting on the body are determined. The 3D SSPP software can assist the analyst in evaluating proposed designs and redesigning the workplace before actually building or rebuilding the workplace or task. The reporting functions implemented in the 3D SSPP program indicate the minimum possibilities of the joints assuming a given position, the amount of pressure on the L4/L5 vertebrae of the spine, the location of the center of gravity, moments and forces acting on the body, and the value of the maximum muscle contraction force expressed as a percentage (MVC – maximum voluntary contraction). After entering the data, the program generates three reports: loads, 3D analyses of the lower back, and a general report (University of Michigan software, 2022).

Workstation and activities selected for analysis

Modern warehouse logistics services currently include transport to and from the warehouse, consolidation (combining small shipments), deconsolidation, order picking, packing, repacking, securing, foiling, labeling, preparing promotional sets, adding instructions, warnings, and marketing gadgets, and distribution to the final recipient. The analyses performed in this research were carried out using a packer's workstation in the warehouse logistics services sector as an example. The most important tasks of the packer included:

- packaging of products,
- repackaging for the marketing needs of retail chains,
- labeling and kit making.

In the processes related to the abovementioned tasks, a human worker is indispensable due to the need for quick changes in the subject of work, as well as the required precision. The standing position of work, which forces the worker to tilt, as well as the manual handling of objects, causes static tension of the muscles. These loads are the greater the longer a person stays in a certain body position. Maintaining it in a long-term manner requires additional tension, leading to severe fatigue in the long term (Teymourian et al., 2021). At the analyzed workstation, the discomfort associated with the work performed had become a factor causing low quality of service, high employee turnover, and an above-average number of sick leaves due to ailments of the workers' musculoskeletal systems. Despite the work of a warehouse operative being strictly related to the lifting and carrying of loads, increased use of the upper limbs, and performing repetitive movements (repetitive work, i.e., monotypic movements), an attempt was made to select a number of critical positions that had the greatest impact on the overall comfort of work at the workstation.

After analyzing the work process of the warehouse operative, it can be concluded that the most common body positions taken during work are sitting, standing, and tilted standing postures. Activities are usually performed under the load caused by the weight of the lifted articles, as well as that from unusual twists of the body. The percentage share of the identified attitudes during warehouse operation is shown in Figure 1.

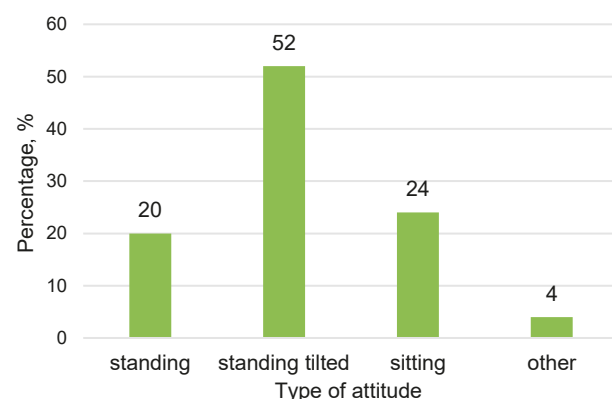


Figure 1. Occurrence of attitudes during the work of a warehouse operative

Overall physical effort is assessed in the sum of static load, energy expenditure, and motor monotypicity (Ignac-Nowicka & Gembalska-Kwiecień, 2008; Ignac-Nowicka, 2017). Regardless of the method of organizing and managing the work of the packer, it is not possible to eliminate the repetition

of movements due to the characteristics of the workstation and the movements necessary to perform activities determined by daily norms. The analyses carried out below were performed to introduce improvements in the workplace in the form of the identification and elimination of excessive strain on the employee's body that could lead to fatigue.

Assessment of static loads using the 3D SSPP tool

The most common positions adopted by employees during warehouse work are the following postures: standing in a tilted position, which are characterized by increased energy expenditure, and a sitting posture. In these postures, work is usually carried out under a load caused by the weight of the lifted objects, as well as that caused by the usual twists of the body. More than half of the total working time involves a position where the muscles of the back and spine must be constantly tense to keep the head tilted past the base of the feet.

At the analyzed packer's workstation, the occurring static loads on muscles increased along with the increase in the weight and size of the packaging units handled. The necessity to transport them by hand, even over short distances, caused significant daily discomfort. During the pallet unloading operation, an employee lifted packages weighing 9 kg.

The analysis of the load simulation was performed for a male employee with a height of 1.75 m and a weight of 84 kg, which corresponded to the 50th percentile group according to the anthropometric atlas (Nowak, 2000).

Load analysis for pallet unloading activities

When the packages were lifted from a pallet, an inclined standing position was assumed in the process of unloading. The worker gradually unloaded the pallet, assuming an ever-lower body position. Due to the low lifting height (about 12 cm above the ground), in the final phase of the activity the worker slightly bent their legs, bending their back at the same time and pulling their shoulder blades and arms forward to grasp the object. Placing many boxes on a pallet often effectively prevented the worker from conveniently gripping the item from underneath. Figure 2 shows the repeatedly observed, incorrect type of object grip used by employees, which put additional strain on the wrists. Figure 2 also contains two 3D SSPP simulation reports generated for this activity.

After analyzing the results of reports generated by the 3D SSPP program for the described activity, significant values of the loads on individual parts of the body were found. In particular, high forces were visible: the total compressive force $F1 = 3778$ N on

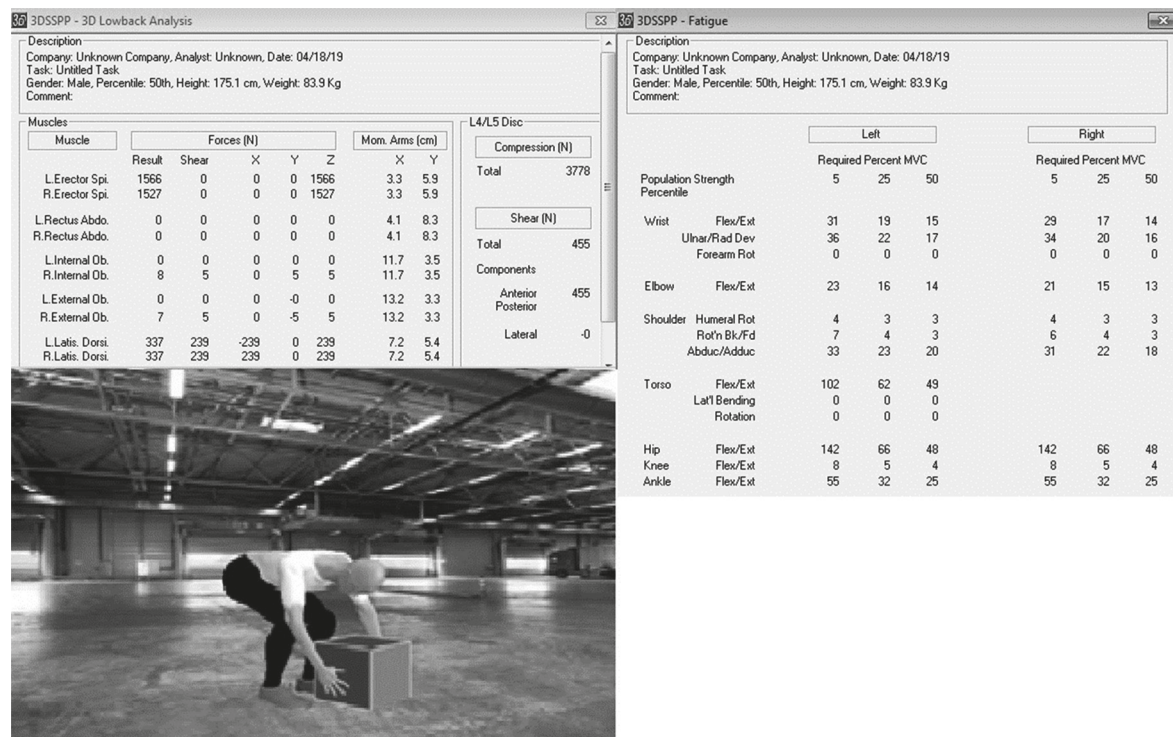


Figure 2. Screenshots of simulation of the loads for inclined standing posture during manual pallet unloading – 3D SSPP reports

the L4 and L5 vertebrae of the spine and the shear force on the L4 and L5 vertebrae with a value $F_2 = 455$ N, mainly in the front plane (the table on the left side of Figure 2). Increased loads resulted to a large extent from the tilt of the torso, which introduced an element forcing a change in the position of the body's center of gravity, and this caused additional difficulties in maintaining balance during the analyzed activity. In the described case, attention is also drawn to the use by the employee of the contraction force of the iliopsoas muscles (MVC = 48%), the contraction force of the torso muscles (MVC = 49%), and muscle force at the level of the ankles (MVC = 25%). On the other hand, the load on the muscles of the upper limbs was less than 20% of the maximum strength of the worker's muscle tension (the table on the right side of Figure 2).

Load analysis for manual transport of packages

The employee, after picking up the carton from the pallet, took it to the workstation. In this phase of the work process, it was observed that the necessity to manually transport the package required a standing-type position in motion. Movement in this position was not forced or restrained in any way and was based on holding and carrying. The back was straight, and the arms kept as close to the torso as

possible, but a load of 9 kg, carried over about 15 m, contributed to general fatigue due to the constant tension of the muscles of the shoulders, forearms, and lower back. In addition, there was a risk of dropping the object on the feet.

The 3D SSPP program load simulation report for manual transport activities is shown in Figure 3. For a weight of 9 kg, the L4 and L5 vertebrae load value obtained in the simulation for the standing-type stance in motion was $F_1 = 1781$ N, while the shear force was $F_2 = 172$ N. In addition, during manual transport, the following loads on the wrists could be detected: left = 33% of the force of maximum contraction, right = 41% of the force of maximum contraction (in the plane of natural wrist flexion). A significant load was also visible in the torso when twisting around the body axis, amounting to MVC = 69% for an employee in the 50th percentile group. The ankle load here reached a significant value of MVC = 32% for the right ankle (the table on the right in Figure 3), but this was a temporary load associated with shifting the weight alternately to individual limbs while walking.

Corrective actions for selected activities

To reduce the static load for the selected activities at the packer's station in the warehouse, changes were made to the position of the body during

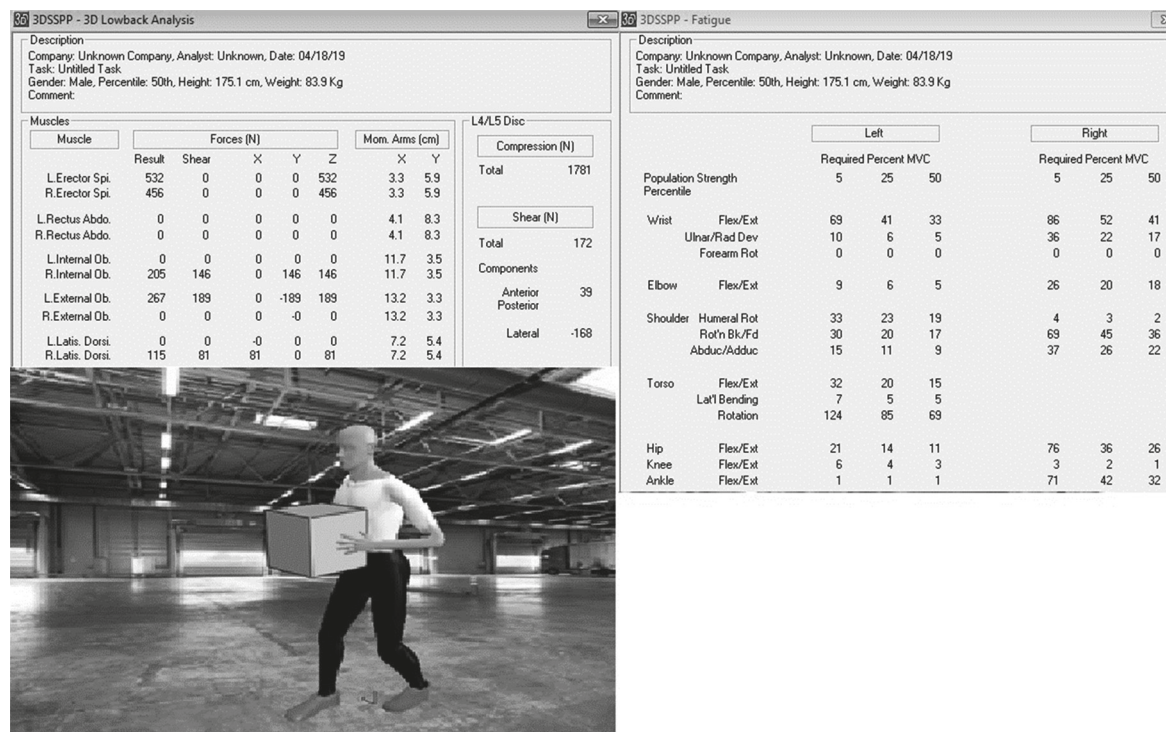


Figure 3. Screenshots of simulation of the loads for standing posture during manual transport of package – 3D SSPP reports

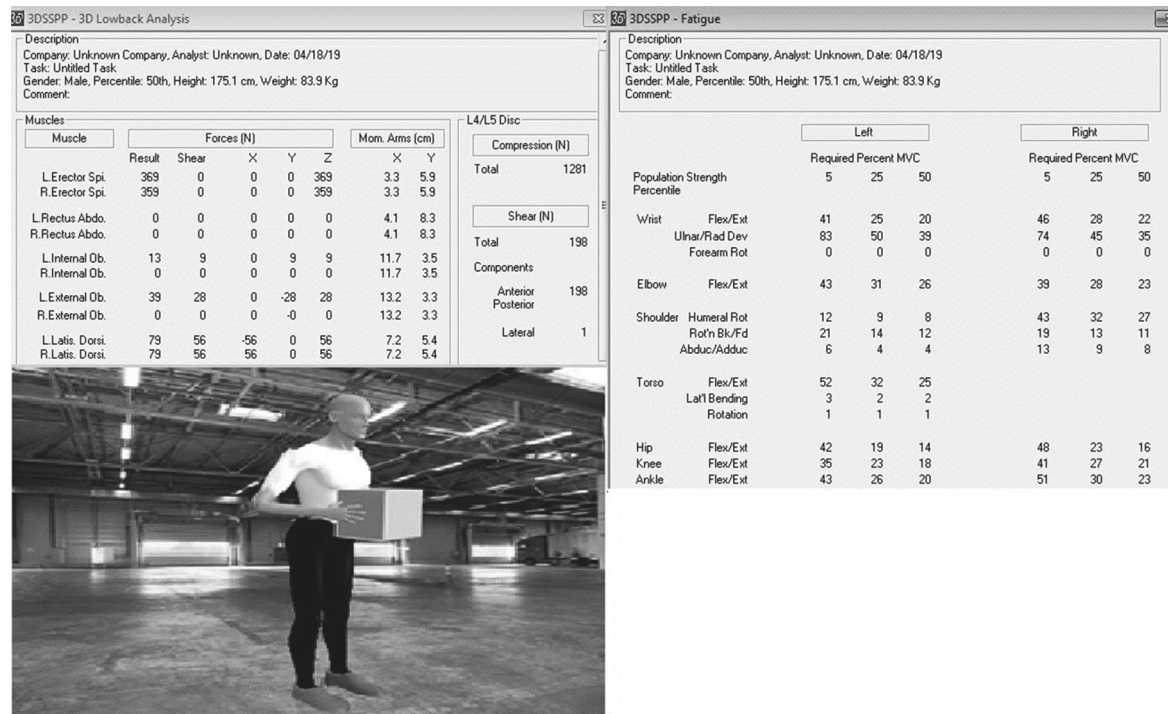


Figure 4. Screenshots of simulation for loads on the corrected standing posture during pallet unloading – 3D SSPP reports

operation, introducing improvements in the form of auxiliary devices. For pallet unloading, i.e., lifting packages from about 12 cm above the ground, it was proposed to use a lifting platform to raise the position of the pallet as it was unloaded. The lift, which contains hydraulic cylinders, can be built into the floor structure and lift objects weighing up to 800 kg on a square platform adapted to the size of the pallets. The platform can also be used to load items onto a pallet. The device in the form of a platform will eliminate the need for the worker to bend over while unloading or loading.

For the modified working posture, i.e., an upright standing posture with a load of 9 kg, a simulation analysis was performed using the 3D SSPP program. The report with the picture of the employee is shown in Figure 4. The pressure force on the vertebrae L4 and L5 decreased almost three times and amounted to $F_1 = 1281$ N, while the shear force now amounted to $F_2 = 198$ N. After introducing an improvement in the form of a platform, the hip load was also reduced from $MVC = 48\%$ to $MVC = 14\%$. The loads on the upper limbs were at a similar level as before the improvement.

For the activity of transporting the packages, it was proposed to use a roller conveyor along the route of manual transport. In addition to relieving the employee during work, this improvement also reduced the time needed to perform this activity. The worker delivers the packaging to the roller conveyor

and pushes the object while in a semi-standing position. In this case, the loads obtained from the simulation with the 3D SSPP program were reduced (from the value of pressure on the vertebrae of the spine L4 and L5 $F_1 = 1781$ N and $F_2 = 1071$ N). The value of the shear force on the vertebrae of the L4 and L5 spine slightly increased due to the need to perform a slight twist of the torso in a semi-standing posture using a high seat. The reduction of loads after the improvement was also visible for the hips, knees, and ankles of the packer.

Conclusions

The analysis of static loads carried out in the study for activities used as examples, such as the manual unloading of pallets and the manual transport of packages by a warehouse packer, revealed significant values of static loads. By using a tool in the form of 3D SSPP software, significant static loads were demonstrated for the manual unloading of pallets in the area of the iliopsoas muscles, the torso, and at ankle level. Moreover, significant effects of compressive and shear forces were found, which overloaded the L4 and L5 vertebrae of the spine. On the other hand, for the manual transport of packages, static loads were detected in the area of the wrists and torso, even with slight twists around the axis of the body, along with compressive and shear forces that loaded the L4 and L5 vertebrae of the

spine. The tool used for the analysis of static loads was also used to search for a modification of the posture and the manner of performing the task in order to reduce the detected loads. The proposed solutions for the two tested activities are characterized by a decrease in the value of the forces developed by an employee and a decrease in the value of loads on the vertebrae of the spine. These improvements resulted in increasing the worker's comfort when carrying out the tasks.

The performed reorganization of the workstation to reduce static loads for selected activities required the use of additional elements in the form of appropriate seats for the employee, additional work surfaces, or simple devices to improve work. To effectively rearrange the workplace and obtain lower values of static loads, it is necessary to analyze the tension of the muscles of the limbs and torso and the forces that affect the skeletal system of the spine. The appropriate 3D SSPP software used (using human anthropometric and biomechanical data) was an effective tool in:

- the assessment of the risk of overloads occurring in some specific activities,
- the optimization of working conditions characterized by static loads.

Application of 3D SSPP software:

- allowed for the precise determination of the values of forces developed by the employee with respect to static loads for selected activities,
- made it possible to modify the posture and the way of performing the task in such a way that a reduction in static load was achieved.

As a result, the analysis carried out using this tool and the introduction of additional elements to the packer's workstation resulted in an improvement in the form of increased work comfort and reduced time for performing certain operations.

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The impact of teaching load on the safety of performing aviation tasks

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Abstract

Flight training is occupied by many hours of theoretical and practical training. Polish universities offer the possibility of conducting the aforementioned training as part of academic training. A young aviation student, implementing himself in this process, takes on the burden of academic training and aviation training. The aviation environment is sensitive to safety issues. These include the occurrence of incidents, events, and aviation accidents. This issue arises directly from the possibility of endangering the health and lives of bystanders as well as aviation personnel and the damage or destruction of aviation equipment. In addition, there are issues related to the immobilization of airports, aviation organizations, excess repairs, or cases settled in court. Despite all the above, it should be mentioned that air transport is described as the safest means of transportation where – although incidents, events, or high-profile crashes are occasionally recorded. It is desirable for personnel to remain as focused as possible during aviation tasks. The multitude of tasks carried out by aviation students, combined with the burden of academic study, can carry a significant impact on maintaining concentration, lowering perception, or at least meticulousness. These topics correlate closely with the human factor. As a research problem, the submitted work was adopted to determine the impact of academic teaching load on the safety of aviation activities performed, in the context of aviation training provided at universities. The research included aviation mechanics and aircraft crews within its scope.

Introduction

The aviation industry is a broad term. More specifically, its scope includes aviation equipment manufacturers, carriers, professional service companies, maintenance organizations, continuing airworthiness management organizations, crew and mechanic training centers, handling companies, air traffic control, and others. Without delving into too much detail, based on the above factors, it is possible

to identify a common feature: the human factor. Regardless of the organization or function, for commercial or private aviation, throughout any aviation task a human is present at every stage. Therefore, it is important to be aware that the innumerable activities in which a mistake or omission can potentially occur can be traced back to the human factor. Nevertheless, air transport is referred to as the safest mean of transportation, in which – although incidents, events or high-profile disasters are recorded from time to

time – there is a downward trend in their occurrence (Quddus, 2020).

Acquiring informed, trained personnel is a long process. Its beginning is the undertaking of initial contacts, industry training, and targeted learning at technical or academic centers by young aviation students. Industry training is frequently characterized by its comprehensive or integrated nature. This feature equally applies to the training of ground maintenance personnel, airport operational services, navigators, and aircraft crews. The time required to obtain the first aviation qualification is measured in hundreds of hours of theoretical and practical training. Expanding on this subject, aircraft crew who obtained their first basic tourist pilot's license (PPL) are obliged to perform a minimum of forty-five hours of flight at an accredited aviation training center (ATO). In addition, such personnel is required to successfully pass nine exams that relate to theoretical knowledge in aviation subjects. The next necessary step to obtain a commercial pilot's license (ATPL) is to undergo a minimum of two hundred flight hours (considering airplane pilots) and the passing of fourteen exams in aviation subjects. At this point, it should be noted that the above information refers to acquiring a pilot's license, while one should be aware that to fully utilize the potential resulting from one's documented authorizations, it is necessary to undertake additional training cycles (e.g., night flying, instrument flying, etc.), and ultimately undergo training for a particular type of aircraft (Announcement, 2021; ULC, 2022).

Next, when considering the case of ground maintenance personnel, the required seniority in the maintenance environment is between one and five years (depending on the category of the aircraft mechanic license) (ULC, 2015). An additional requirement is theoretical examinations in twenty-one training modules. It should be noted that this number represents the value of all possible examinations. Their number varies for different license categories. The career path of an aircraft mechanic, conducted at centers with approved training organizations according to PART-147 regulations (Regulation, 2014), obliges practical training close to 1200 hours, depending on the theoretical training factor used.

Accounting for the above information, flight training is occupied by many hours of theoretical and practical training. Due to its duration, there is a tendency for the candidate to start at a young age, which enables a staggered distribution of knowledge and skills. Polish universities offer the possibility of conducting the aforementioned training as part

of the academic training. A young aviation student, implementing himself into this process, takes on the burden of academic training and aviation training.

Nowadays, employers recommend that personnel demonstrate a high level of abilities; it is also essential to have a license, training, and education. Bearing in mind the responsibility for passengers and bystanders, and property disposed of by operators, it should be noted that the working environment of personnel from the aviation environment is not lax. The industry in question expects its personnel to simultaneously perform (often several) tasks, have an insensitivity to stressful situations, composure in contentious or dangerous situations, and have knowledge or teamwork skills. The above can be supplemented by the quality of the product expected by the recipient, in the form of an aircraft received after maintenance or a punctual and safe flight.

Advances in technology, given the field in question, lead to operational implementations of other types of aircraft, new solutions, or modifications to existing ones, and the introduction of corrections or removal of revealing design flaws, which are issued in the form of service bulletins or airworthiness directives. This situation directly affects crews, ground technical personnel, and airport operational services. The above factors force personnel to continuously improve their qualifications, retrain, and participate in external training, while also requiring the renewal of already possessed training and authorizations.

Yet another issue one can cite is the changing airspace. Such a state of affairs arises as a result of changes, if only due to the appearance of terrain obstacles, which should include both artificial and natural scenarios. Such changes are reflected in the updates to aeronautical maps and issued dispatches. They can refer to changes in flight paths, aircraft approach paths, or taxiways. The introduction of updates to maps issued in the traditional way, as well as electronic forms, implies the obligation of crews to familiarize themselves with such information and immediately put it into use, directly affecting the performance of flight operations.

Given what has been outlined above, the excessive mental and physical workload associated with learning a job – including participation in aviation training, combined with the intensity associated with taking academic courses – can be a key factor affecting the safety of performing aviation activities in any aviation-related professional group. It is also pertinent to mention that, given the goodwill of young aviation adepts, an additional factor that can affect

conduct during training is premature professional burnout.

In general, the topic of occupational burnout has been extensively covered in previous works (Bilska, 2004; Sęk, 2004; Kamrowska, 2007). The topic of preventing and managing professional burnout is taken up by (Bilska, 2008; Maslach, Leiter & Braksal, 2010). The aspect of stress occurring in this situation, in turn, is the subject of other publications (Terelak, 2001; Litzke, 2007). In a different context, the impact of stress on aviation personnel is analyzed in previous work (Macander, 2016), which focussed on aviation accidents as a source of stress disorders in pilots. The human factor in aviation is widely taken up by publications (Dąbrowska, 2011; Makarowski, 2012) and concerns the process of flight training (Makarowski & Smolicz, 2016). Analysis of the human factor in aviation accidents is also the subject of earlier works (Truszczyński, Tarnowski & Biernacki, 2008; Beaty, 2013; Lasota, 2018).

In (Peruń, Stołtny & Urzędowski, 2021) the aforementioned issue is addressed. The possibility that professional burnout may affect the safety of performing flight operations is commented upon at the same time, and other factors affecting the issues raised are also indicated. The authors point to age, seniority, or stress. A similar issue was raised in (Stołtny & Peruń, 2021), where the authors examined a possible link between overstress and safety. Existing publications in this area mainly concern surveys among pilots and mechanics, after the training process has been completed. Within the scope of this work, the main focus is on the impact on the safety of performing aeronautical tasks of the training process itself, which takes place during the implementation of the educational process at universities. This involves a greater number of teaching duties for the trainees and affects their workload, thus increasing the risk during their various aviation operations.

It is also important to present research (Bavafa & Jónasson, 2021) that shows that fatigue affects employee performance. This information should be considered important for an improved understanding of the training situation faced by young aviation students. Next, the authors (Grady et al., 2022) discussed the effect of high energy levels (the opposite condition for fatigue) on the conscientiousness of task performance. In the industry under discussion, this trait can be seen as crucial due to the importance of possible consequences in case of negligence. It is presented that fatigue (a lower energy level) decreases accuracy, successively higher conscientiousness of the worker increases accuracy and, importantly,

the interaction between their energy levels and conscientiousness is also indicated.

The problem of personnel training can also be analyzed in another sense – how training in the profession affects aircraft maintenance times. This topic was addressed in the work (Atici & Şenol, 2022), among others. A model is presented that can be effectively used to plan aircraft maintenance, which evaluates the performance of certified personnel and maintenance training. It is proposed that aircraft maintenance activities are plannable based on a learning effect that achieves a more realistic maintenance plan.

The problem of training during the Covid-19 pandemic was described in a previous paper (Ng, 2022) using the example of Hong Kong in China. Despite the widely addressed topic of safety (Jancelewicz, 2009) and risk management of aviation hazards (Szymaniec, 2018), aviation accidents and disasters still occur, including during personnel training. Hence, it is imperative to conduct research that can improve this situation.

Characteristics of the study

Today, considering the geopolitical situation and the SARS-CoV-2 virus pandemic, it can be seen that the situation in many industries has changed compared to the years before 2019, including the aforementioned aviation industry. In particular, accounting for the preservation of common rules against the spread of the cited virus, remote work has become widespread. This form of work has covered numerous positions and industries. Adjusting to the above circumstances, the survey presented in this work was conducted electronically. The questionnaire submitted to the respondents was anonymous and participation in the research was voluntary.

Questionnaire

The form acts as an in-house study that explores the topic at hand. It consists of closed questions only, constructed in such a way as to examine the correlation between teaching load and the safety of aviation activities as definitively as possible. The survey consisted of seventeen single-choice questions, in which emphasis was placed on addressing only the necessary number of questions. Such a procedure was intended not to lead to a situation in which the respondent would be discouraged from continuing to fill out the form or abandon answering altogether. The form did not include the use of graphics.

Selection of the study pool

To select an adequate pool of respondents, factors that have a key impact on the topics explored were determined, namely active participation in:

- taking academic courses;
- flight training (theoretical and practical) for crews, as well as for ground maintenance personnel.

Individuals who did not meet at least one of the above conditions were excluded; thus, aviation professionals who work in aviation industries were not invited to the survey. Instead, aviation students of both first- and second-degree courses in aviation, whose academic groups participated in the industry training process, were asked. Respondents to the survey represent two groups: aircraft crews attending training at an Approved Training Organization center, and ground maintenance mechanics attending basic training on behalf of a technical staff training organization certified according to the PART-147 regulations. The level of training among students did not affect participation in the study. The authors did not introduce an upper age limit, while the lower age limit was determined with respect to the start of the academic study. Both women, men, and non-binary participants entered the study. The percentage distribution of the study groups is presented below.

Summary of collected results

The pool of survey participants was 76; it should be noted that the vast majority of the respondents are directly involved in the subject of the presented article. Due to the number of respondents, the presented survey results should be considered preliminary. It is planned to continue them in future years using a broader scope. The results obtained, as well as the conclusions drawn from them, are presented in this section. It was assumed that each paragraph is a presentation of the results concerning one question. The percentages of the obtained answers were rounded to a whole number, the sum of which was not always 100% in each case.

The construction of question 1, and the possible distribution of responses, are shown in Figure 1. Among the surveyed pool, 80% were male and 17% declared a female gender. Among the participants, 1% were non-binary people and 2% of the respondents did not select any answer, which may suggest that these people identify their gender differently than the survey predicted.

Figure 2 refers to the next question. It raised the question of the age of the respondents. The results

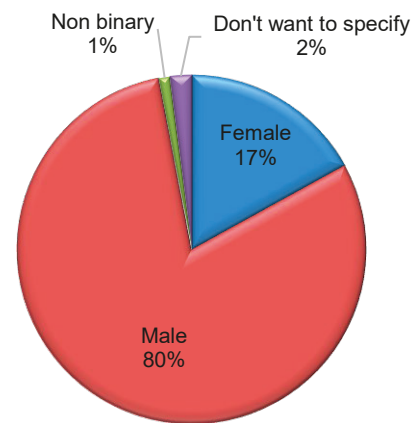


Figure 1. What is your gender?

collected show that a large proportion of those involved was aged 23–26 (47%). The second largest age group is those between 18–22 years old (43%). The following age groups, in terms of numbers, are ranked next: over 30 years old (5%) and 27–30 years old (3%). The group of respondents who did not respond accounted for 2% of the pool and those under 18 are 0%.

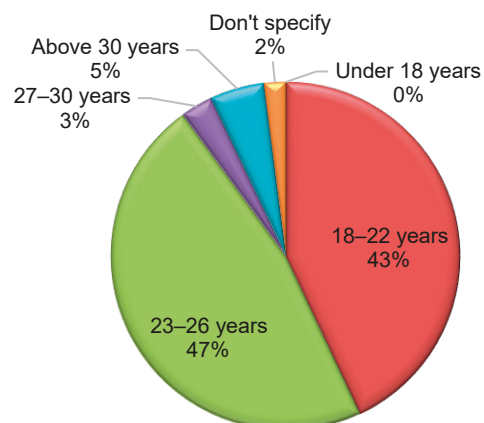


Figure 2. What is your age range?

The overwhelming majority of those interested proclaimed that they were a student of an aviation faculty (99%), whereas 1% of the pool did not indicate an answer. The ratio of the distribution of responses to the third question may indicate that, in the case of the last-mentioned answer, the research team is potentially dealing with a statistical error. Another large group (among the 99%) of declared aviation students is aviation mechanics students. It is a group containing 88% of the studied pool. This was followed by air navigation/pilotage (9%) and other (2%). The results discussed above are summarized in Figures 3 and 4.

Among 99% of the aviation students, 93% of them indicated that they were involved in aviation

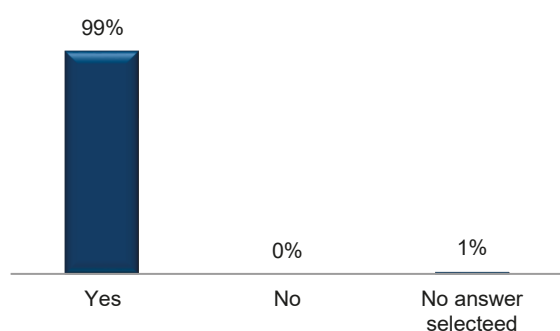


Figure 3. Are you a student with an aviation education?

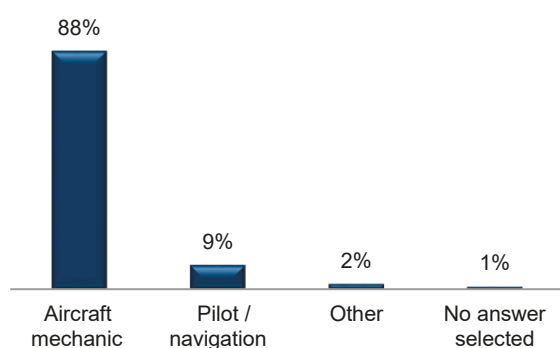


Figure 4. What is your field of aviation education?

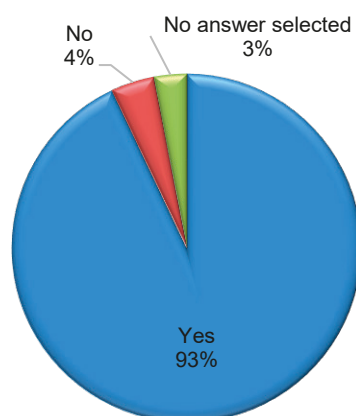


Figure 5. Are you involved in aviation training?

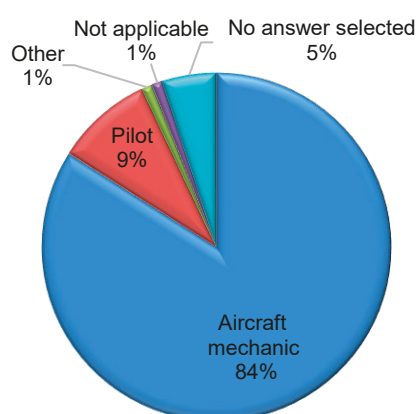


Figure 6. What is your aviation training direction?

training. 4% of the respondents said they did not participate in such training (Figure 5). Subsequently, 84% of the group said they favored engaging in industry training related to aviation mechanics (Figure 6). In comparison, 9% of the respondents chose the answer that indicates active participation in flight crew training. Only 1% indicated a different orientation, while 1% indicated that the question did not concern them. 5% of the pool did not choose an answer from the available options.

Figure 7 presents a summary of responses to the question relating to the period of work of the respondents in aviation. The most numerous group entails people whose involvement in the aviation industry is 3 to 4 years. The results show that this group is 43% of the respondents. The second most numerous group relates to over four years (32%). It is followed by 1 to 2 years (17%) and less than a year (4%).

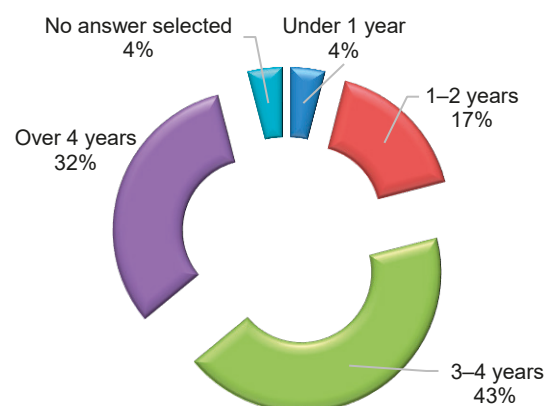


Figure 7. How long have you been involved in aviation?

Figure 8 shows the situation related to their feelings towards the undertaken training. Considering the overwhelming number of positive responses (86%), it can be stated that, using a colloquialism, “students like what they do”. In addition, 8% of respondents believed it is difficult to say whether they like their aviation training course, while 4% refrained from expressing their opinion on this question.

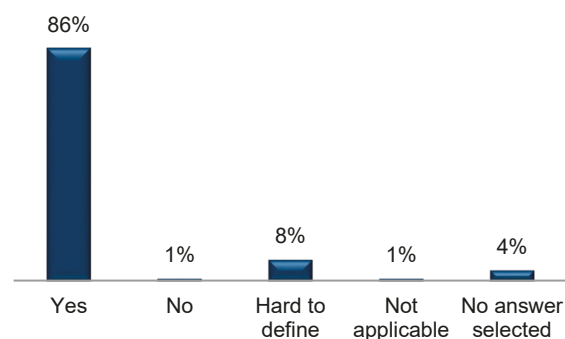


Figure 8. Do you like your aviation training course?

Figure 9 shows the distribution of the results for the question: “How large do you think the teaching load is relating to your studies?” Next, question 10 is: “How large, in your opinion, is the burden related to the conducted aviation training?”. This is a crucial question, considering the distribution of responses to questions 5, 6, and 8. Even though the vast majority of respondents:

- participates in academic education concerning aviation courses;
- takes part in industry training;
- likes his targeted course.

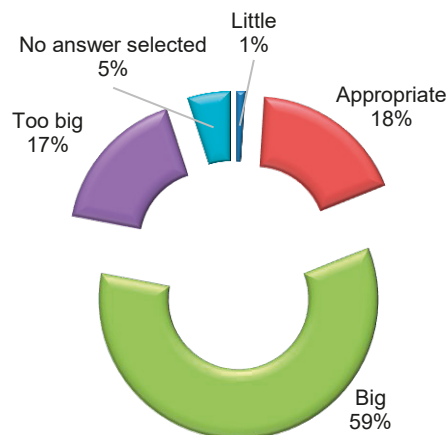


Figure 9. How large do you think the teaching load is relating to your studies?

The collected results related to questions 9 and 10 may indicate a high level of didactic load, taking into account the entire commitment. The respondents indicate a “large” teaching load, which originates from the academic study (59% of the respondents), and the “heavy” burden related to the flight course (42%, Figure 10). Subsequently, 17% of respondents believed that the academic burden, as well as

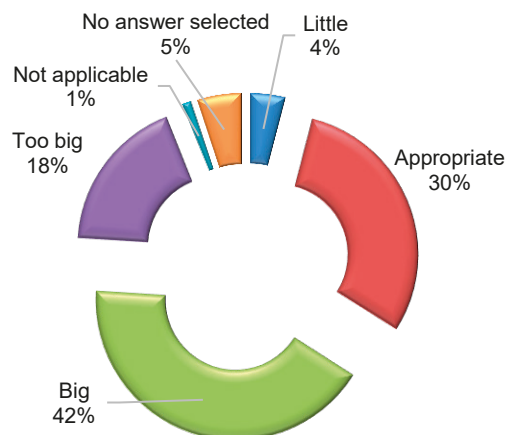


Figure 10. How large, in your opinion, is the burden related to the conducted aviation training?

that of training (32%), is “too great”. Only 18% of the respondents (Figure 9) and 30% of them (Figure 10) replied that the burden from their sciences is appropriate.

The situation presented in Figure 11 is similar. Here, 41% of the respondents believed that they often find themselves in a situation where they participate in training while tired. In addition, 37% of them are sometimes tired, while 8% of respondents think that they are constantly tired in class. It should be emphasized here that the trainees perform aviation activities, and the state of fatigue significantly affects the safety of the human factor. Despite the results obtained in question 11, 79% of students declared that they did not witness an incident during their flight training in which other people were involved in the training (Figure 12). On the other hand, 14% of them witnessed such an incident.

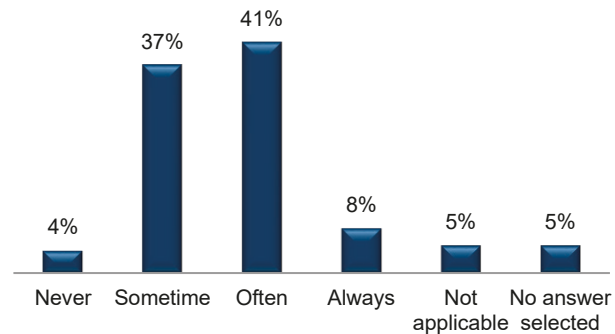


Figure 11. How often do you attend aviation training while being tired?

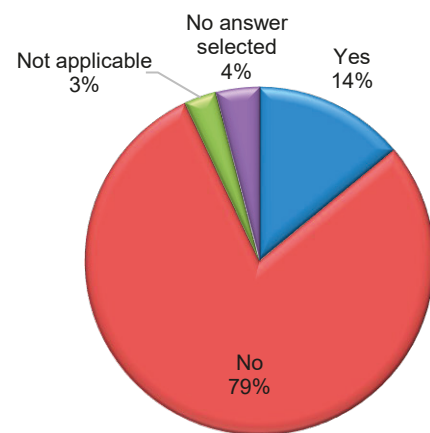


Figure 12. Have you witnessed an incident during flight training attended by other people?

Despite the frequent fatigue of the apprentices (Figure 11), only 14% of the respondents observed incidents caused by other trainees (Figure 12), while only 1% of the respondents declared that their actions led to the incident (Figure 13). Despite the entire situation described here, as many as 17% of

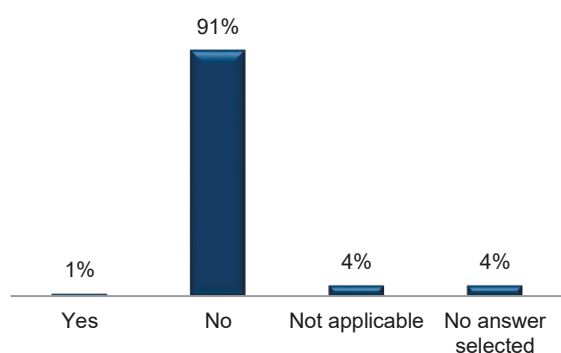


Figure 13. Have your actions led to an incident during flight training?

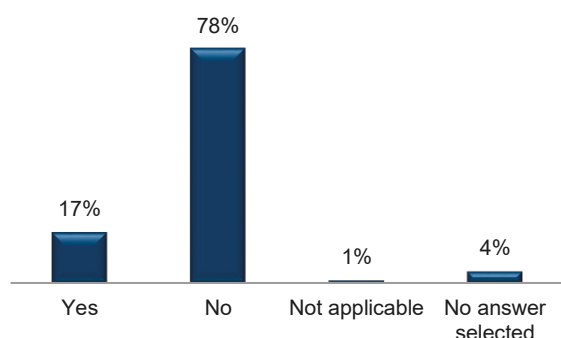


Figure 14. Have you witnessed a dangerous situation during flight training in which other people involved in the aviation training participated?

the respondents answered positively to the question regarding the observation of the occurrence of dangerous situations (Figure 14). There seems to be a certain dissonance between declarations about introducing dangerous situations and witnessing them.

The dissonance referred to above is somewhat confirmed after analyzing the results, when comparing the above figures with the results presented in

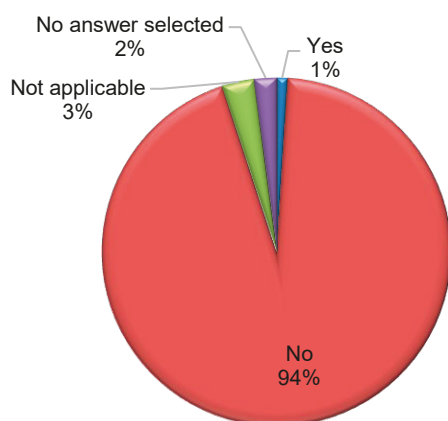


Figure 15. Have your actions led to a dangerous situation during aviation training?

Figure 15. Only 1% of the responses indicated an awareness that a trainee's action led to a dangerous situation during the performance of aviation activities.

Another important issue is illustrated in Figure 16. This question correlates with the topics discussed in Graphs 9, 10, and 11. 70% of responses to question 16, according to respondents, indicated a relationship between the total training burden and the safety of aviation activities. This is consistent with the results presented in the discussion of the above figure.

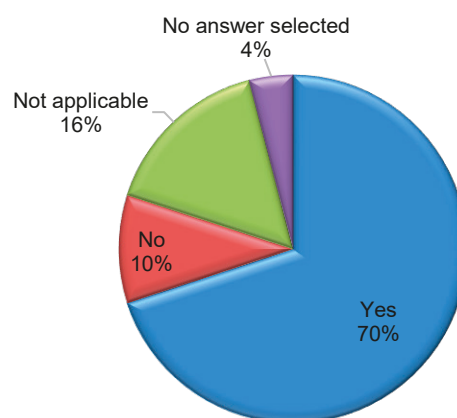


Figure 16. Do you think there is a correlation between academic burden, training, and behavior safety during the activities related to aviation training?

Figure 17 presents the distribution of responses to the final question included in the survey. This question concerned the impact of training intensity on the safety of aviation activities. The answers, as was the case earlier, are consistent with the collected results relating to the following questions: 9, 10, 11, 16. According to the respondents, 78% of the answers are affirmative.

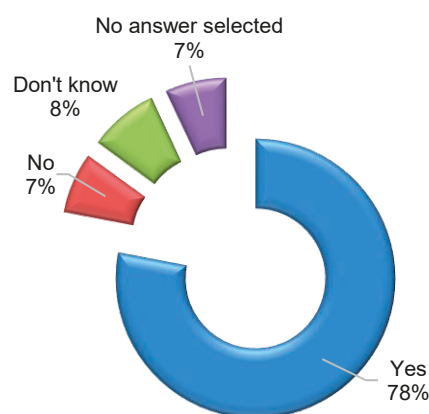


Figure 17. Do you think the training intensity may impact safety during the performance of aviation activities?

Discussion

The survey results presented in the previous section first show a general picture of the people interviewed. The vast majority of responses during the survey were given by men. The age of the respondents in the range 18–26 years was indicated by as many as 90% of people, while older people were only 8% of the respondents. However, based on these surveys, it cannot be concluded that there is no interest in aviation training among older people, as the place of surveying and the correlation with the age of those pursuing their higher education has a direct impact on the results here.

All the respondents are students of aviation specialties, as the survey was directed to them. However, since the human factor is a significant problem in other industries, it is possible to conduct similar surveys in other industries that require intensive training, which can be performed in parallel with the standard educational path. It can also be noted that the survey was mainly taken by students of one of the two aviation specialties, in which training is conducted at the Silesian University of Technology, specifically, the aviation mechanics specialty. Since training in the specialty does not necessarily occur with simultaneous training outside the university, a few percent of respondents declared that they do not participate in such training.

Further survey results, indicating the period of involvement in aviation-related activities, are also interesting. The period correlating with the time of the beginning of studies (and later) is indicated by 21% of people (involvement up to 2 years) and 64% (up to 4 years). More experience is shown by 32% of the respondents, whose involvement is estimated at more than 4 years. From the point-of-view of the research conducted, the most relevant seems to be the answers on the degree of teaching load associated with the studies themselves and, separately, with flight training. In the first case, the answers “high” and “too high” are indicated by about 75% of people, while “adequate” and “low” are indicated by 19% and 34%, respectively. Unfortunately, according to the authors, this also results in people participating in training in a fatigued state too often. The survey participants revealed a correlation between the burden of studying and concurrent training, as well as the intensity of the training and staying safe during the activities provided for in the training. For this reason, it seems reasonable to take measures to improve the safety and efficiency of the training provided. A similar problem, with a completely different

reference, is presented in the publication (Tuasikal et al., 2021).

Conclusions

Averaging the presented research results, which should undoubtedly be treated as preliminary due to the number of respondents, shows a picture of a man between the ages of 18 and 26, as previously indicated. The average result also suggests that this person is a mechanics and aeronautical operation student, who has engaged in industry-specific aviation training in aviation mechanics. The average respondent has been associated with the aviation industry for 3 or more years.

The academic workload, and the burden related to the conducted aviation training, are defined as high. The respondents indicated that they take part in aviation training while being tired. This may indicate that this condition is caused by the study load as well as the training intensity, or a combination of both. The respondents answered that there were air incidents involving people participating in the training. The indicated percentage can be considered significant, given the instructor’s supervision over the apprentices.

Among the results, there are some discrepancies between the thematically related questions. This situation may result from several factors, among which we can distinguish the following: low involvement in research, lack of willingness to answer in line with the actual situations, poor sense of the importance of safety in the aviation industry, willingness to conceal facts, lack of understanding of the questions, and disregard for both the research surveys and the actions taking place during the training. Most respondents believed there is a correlation between the study, training, and safety burden. Training intensity was indicated as the main factor of the obtained results.

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Barriers impeding introduction of autonomous vessels

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Abstract

Today's shipping industry is experiencing a shortage of properly trained and competent deck and engine officers. This problem is becoming more acute with each passing year and traditional methods to resolve it apparently do not work. It has become obvious that cargo vessels must be less dependent on human operators. The solution lies in the replacement of manned vessels with autonomous ones. The introduction of autonomous vessels encounters several barriers, which need to be analyzed to find ways to overcome them. It requires a multi-pronged analysis of existing regulations, technical limitations, cyber security, and co-existence of manned and unmanned vessels in waters with dense traffic. The most difficult problems lie in international regulations, which were written for manned vessels only. Such rules need to be reworked before the deployment of autonomous vessels can be sanctioned worldwide. Technical issues are being gradually resolved with the introduction of new technologies. Special attention should be given to the cyber security of autonomous shipping as it requires the transfer of very large amounts of data through wireless networks. Accommodation of manned and unmanned vessel traffic may require a new approach for ship routing to separate both kinds of traffic.

Introduction

For a few years, several countries and organizations have conducted studies on the development of technologies important for autonomous vessels, as well as international regulations governing future vessels. The most well-known research programs were MUNIN programs (Maritime Unmanned Navigation through Intelligence in Networks) conducted in the European Union (MUNIN, 2022) to develop the concept of the autonomous vessel and the Yara Birkeland project (YARA, 2022). MUNIN was completed in 2016, and a lot of valuable insights were obtained related to technologies for autonomous vessels. Norwegian project Yara Birkeland brought to life the first zero-emission, fully autonomous vessel

scheduled to be fully operational in 2022. She was officially christened on 29th April 2022. In Poland, in the years 2017–2020, a research project was carried out involving Autonomous Vessels with an Air Look (AVAL). The experimental parts of this project were conducted with the participation of The Foundation for Safety of Navigation and Environment Protection, owned by the foundation Shiphandling, Research and Training Centre in Iława, Poland (Ship Handling Centre, 2022).

Personal experience gained when working on the project AVAL helped to focus attention on the introduction of problems due to autonomous vessels. All these projects were aimed at research in the field of new technologies. Examination of regulatory issues was pioneered by Danish Maritime

Authorities with a thorough analysis of international and Danish law published in 2017 (Danish Maritime Authority, 2017). In the same year, IMO (International Maritime Organization) began its regulatory scoping exercise on Maritime Autonomous Surface Ships (MASS). The exercise was completed in 2021 (IMO, 2021), and it became the base for the preparation of the non-mandatory MASS Code to be introduced in 2024; it was followed up by a mandatory code in 2028 (IMO, 2022). Existing analyses only focus on regulatory problems, so a wider approach is necessary. Indication of problems laying ahead for autonomous vessels was given in the article “*Problemy rozwoju statków autonomicznych*” (“Problems of Development of Autonomous Vessels”) (Zalewski, 2020) with similar conclusions. Years spent at sea as a master and offshore installation manager provided practical knowledge of the problems, which may delay the deployment of autonomous vessels on a mass scale. The provided analysis aims to determine the causes of the growing interest in autonomous ships and to find hindrances that may delay operation of such vessels.

Primary factors fostering the development of autonomous vessels

Due to a growing world cargo fleet, a search for how to improve the safety of its operations and productivity has been undertaken for several years. One perspective method is to follow the path of automatization of operations in the form of autonomous vessels. Today, the shipping industry has three strong stimuli to develop and implement such vessels. The first aims to improve safety of navigation by a limitation or complete removal of human factor, which is considered as the predominant cause of shipping accidents. The second stimulus is purely commercial and comes down to the elimination of high crewing costs from the vessel's budget. The third reason for autonomous vessel operations is a continuously increasing shortage of competent crewmen, particularly deck and engine officers. Besides this, shipowners expect to achieve several gains, such as increased productivity and integration of their vessels with land-based automated transport systems. Designs of new types of vessels will consider more types of alternative fuels and increasingly efficient propulsion systems. Terminals designed specifically for autonomous vessels will simplify mooring and unmooring operations, which will optimize the cargo handling processes.

Role of the human factor in shipping accidents

For the last decade, safety at sea has increased beyond any doubt. The amount of totally lost vessels dropped more than twofold. Statistics of the AGCS (Allianz Global Corporate & Specialty) have registered 127 total losses in 2012 and only 54 of them in 2021 (AGCS, 2022, p. 12). It is a positive trend showing the effectiveness of new safety regulations. However, not all catastrophic events like multiple casualties, environmental pollution, or substantial financial loss ended with vessel loss. In pursuit of better economics, the size of the vessels is continuously growing, which means maritime accidents are becoming more acute than before in all aspects. Several studies found human factor as crucial aspect of accidents at sea. Data provided by the EMSA (European Maritime Safety Agency) (EMSA, 2022, p. 38) points to 65.8% of maritime accidents being caused by human error. Earlier research conducted in Canada and Atlantic Europe attributed human factor as the cause of 80% of maritime accidents for 2012–2015 (Cordon, Mestre & Walliser, 2015). This study also provides the main constituents of accidents as human factor; the number of cases in the analyzed reports is shown in Figure 1.

Situation awareness is the highest position for accidents caused by human factor when broken down into its components. This also tops a list of “The Deadly Dozen” published by the UK MCA (UK Maritime and Coastguard Agency) (UK MCA, 2016). The UK maritime authorities have named 12 elements of human factor that are responsible for accidents. A loss of situation awareness means that humans can often lose the overall picture of a complex situation and make erroneous decisions leading to accidents. A second leading position for human factor is a breakdown in work practices due to not following procedures and taking shortcuts, which are frequent cases. The introduction of decision support systems, and a gradual move toward fully autonomous vessels, should cure these problems.

High crewing costs

Shipping companies seldom publish information regarding their budgets since they are trade secrets. Available information is scarce but allows for a rough estimate of what part of the ship's budget constitutes the cost of hiring and supporting a crew. Several maritime research and intelligence agencies sell professional reports on world shipping, which

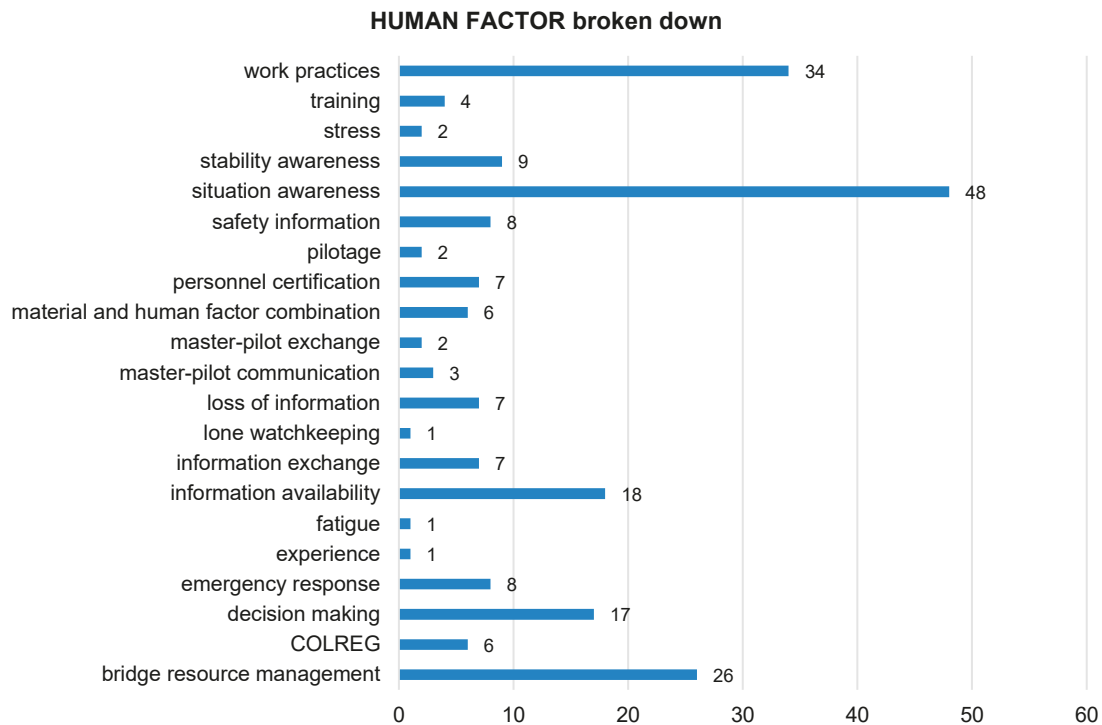


Figure 1. Constituents of human factor in maritime accidents (Cordon, Mestre & Walliser, 2015)

are used for maritime market analysis. Iconography from such a report is shown in Figure 2.

According to this information (Clarksons, 2017), the shipping industry spent almost 53% of its operating costs on wages and crew support in 2016 (before the Covid-19 outbreak). In 2019, the marine education and training platform Marine Insight published an analysis of the operational cost for the Handymax

size bulk carrier, where crewing costs comprised almost 55% of the total running costs (Dsouza, 2019). During the Covid-19 outbreak, crew change costs sharply rose due to restrictions on personnel movement and the necessity of quarantine. Portal Seatrade-Maritime reported an expected rise in crewing costs by 10–15% due to the pandemic (Hand, 2020). Shipowners are expecting to make huge savings due to a partial reduction of the personnel onboard or elimination of the need for a crew at all.

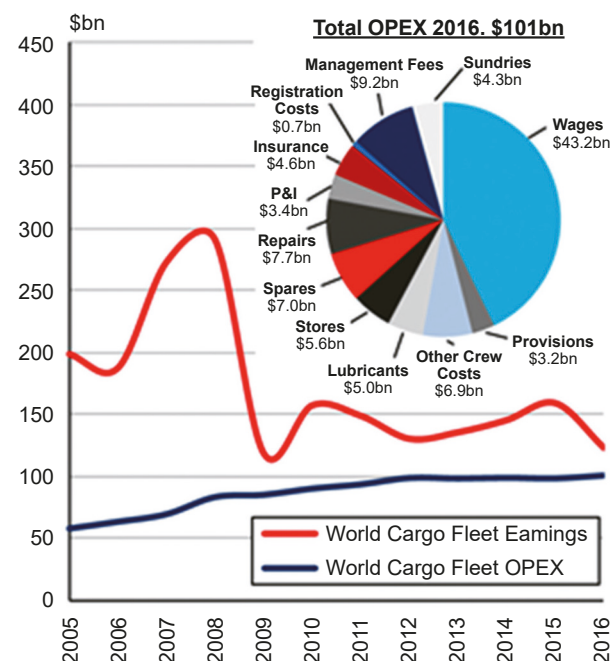


Figure 2. Breakdown of the global cargo fleet operating costs (Clarksons, 2017)

Competent crew shortage

In 2016, the Baltic and International Maritime Council (BIMCO) and the International Chamber of Shipping (ICS) published a forecast regarding the demands for seafarers in the incoming years (Safety4sea, 2018). A graphic presentation of this forecast is given in Figure 3.

It has been estimated that a shortfall of officers will reach 92,000 in 2020. The new BIMCO/ICS Seafarers Workforce Report was published in 2021 (ICS, 2021). This report provided corrected figures with a current shortage of officers amounting to 26,240, but nevertheless, it warned shipowners about a serious shortage looming in 2026. Shipping companies are now facing not only an increased rise in crewing costs, but also the prospects of increasing wages to attract more seafarers and reduce workforce turnover at the expense of their profits.

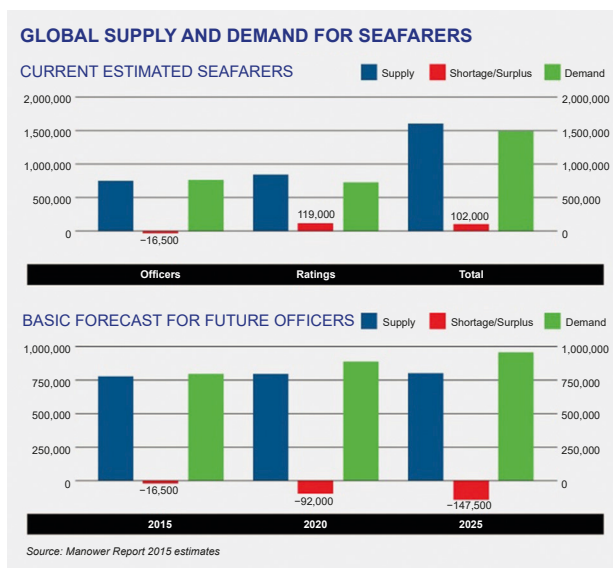


Figure 3. A growing shortage of marine ratings and officers (Safety4sea, 2018)

Main barriers hindering the utilization of autonomous vessels

Moving towards autonomous vessels is widely perceived as the future of the shipping industry, but the use of such vessels needs to overcome several obstacles. The first type of problem is typically technical. Autonomous vessels require the adoption of several new and advanced technologies to make such ships remain as they currently operate. For the time being, the safety of the vessel is accomplished by the presence of the crew on board. The ship's systems responsible for navigation, propulsion, and cargo handling are built to be operated and supervised by humans. Depending on the degree of autonomy, such systems need to be re-designed for autonomous

operations with human senses being replaced by an array of sensors. The rapid development of technology during the last decade enabled an assumption that all technologies needed to fulfill all the tasks of vessel safety are presently available. Growing demand for them further promotes their development and mass production. Shipowners are expecting that a reduction in the crewing expenses will offset an increased cost of new vessels. Taking all the above into consideration, it can be said that technology is not a significant obstacle in the way of the development of autonomous vessels.

More serious problems arise with the existing international and national regulations. All rules in force today were written for fully manned vessels. Many regulations require continuous control of vessels by certified crew members. The only viable solution to regulatory problems is amending and re-writing current international rules governing maritime shipping, as a basis for modifying national regulations. In 2017, the Danish Maritime Authority published a report analyzing the main regulatory barriers for autonomous vessels (Danish Maritime Authority, 2017) and identified their main categories, as shown in Figure 4.

The division of the regulatory barriers into seven categories sets a logical framework for the following analysis of each hindrance (identified earlier) for autonomous vessels.

Jurisdictional issues

Articles 21, 22, and 25 of the United Nations Convention on the Law of the Sea (UNCLOS) granted coastal states several means to exercise their jurisdiction within territorial waters (UN, 1982).

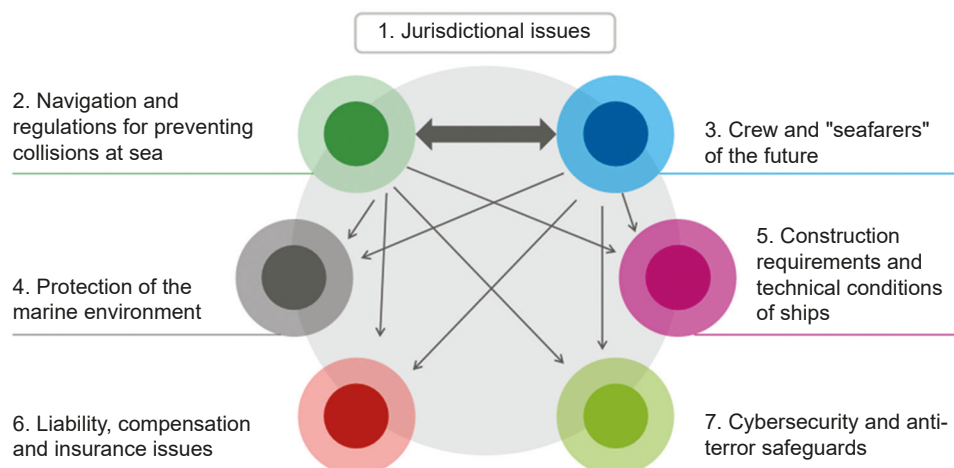


Figure 4. Regulatory barriers (Danish Maritime Authority, 2017)

States have the power to adopt laws to protect the safety of navigation, while also preventing accidents leading to environmental pollution or limiting movements to designated lanes. Today, most coastal states are members of several MOUs for regional cooperation that ensures better control of the compliance of ships with international regulations (IMO, 1991). Vessels not in compliance with international and local regulations can be denied the right of innocent passage, not only through the waters of a particular state but a group of coastal states cooperating in an MOU. It could be a severe setback for remotely controlled or fully autonomous vessels. The lack of a master, who acts on behalf of the vessel and ship-owner, onboard an unmanned vessel also creates problems with local maritime authorities, customs authorities, and law representatives. For remotely controlled vessels, the coastal state may not agree to have the activity of foreign centers in their waters. Such problems can be resolved by providing some crew on board for certain legs of the voyage, providing a local representative for the vessel and, when necessary, transferring the remote control of the vessel to a local control center.

Navigation and regulations for preventing collisions at sea

Unmanned vessels cannot comply with current regulations of the Convention on International Regulations for Preventing Collision at Sea (COLREG), 1972 (IMO, 2017a), the International Convention on Standards of Training, Certification, and Watchkeeping for Seafarers 1978, and the Seafarer's Training, Certification, and Watchkeeping Code (STCW 1978/95) (IMO, 2017d). Rule 5 of COLREG requires the maintenance of a continuous look-out by sight and hearing. The rules were written half a century ago; the only way to fulfill these requirements was to keep watch on the bridge all the time. For vessels with reduced crews, this rule can be interpreted with reference to the transmission from suitable sensors allowing the crew members to stay outside of the bridge and still comply with Rule 5. Remotely controlled and fully automated vessels cannot comply with this rule at the present time. STCW Convention and Code contain even more strict rules regarding watchkeeping on the bridge and in the engine room. Regulation VIII/2 of the STCW Convention requires the physical presence of a watchkeeping officer on the bridge at all times during his watch and an engineer to be physically available in the engine room when required. The same conditions

of watchkeeping are repeated in the STCW Code in Section A-VIII Part 4-1. For the time being, autonomous vessels are tested within internal waters, where international rules are not applicable. Allowing such vessels to use the shipping lanes may lead to the collision with manned ships with crews not accustomed to their presence. Autonomous vessels operate within the constraints of their programs, and it is difficult to predict what action the crew may undertake. Separate lanes for manned and unmanned traffic could solve this problem, but there is not always sufficient space for it. Relaying control of an unmanned vessel to a local center may help to alleviate this situation.

Crew and the "seafarers" of the future

Regarding the manning of the vessels, UNCLOS Article 94 requires that "each ship is in charge of a master and officers who possess appropriate qualifications, in particular in seamanship, navigation, communications, and marine engineering" and "that the crew is appropriate in qualification and numbers for the type, size, machinery, and equipment of the ship" (UN, 1982). This rule can be extended for remotely controlled vessels with a person acting as a master ashore, but fully autonomous ships cannot comply with it. UNCLOS also calls for a master to render assistance to shipwrecked persons, which may be difficult for fully autonomous vessels without the development and introduction of new technologies, e.g., marine rescue drones.

Protection of the marine environment

Operations of autonomous vessels with reduced crew and unmanned is expected to limit environmental impact, due to the reduced discharge of garbage and sewage. Yet there remains an open question regarding the ability of unmanned vessels to cope with pollution from their own oil tanks and cargo. For the time being, there is no practical solution in the form of equipment capable of containing and cleaning up spillage without a crew. Without solving this problem, it might be difficult to prove that unmanned vessels represent the same level of environmental protection as their manned counterparts. The obligation to report incidents that may result in pollution also needs some attention. The International Convention for the Prevention of Pollution from Ships (MARPOL) (IMO, 2011) Protocol 1 Article 1 and the International Convention on Oil Pollution Preparedness, Response, and Co-operation (OPRC) (IMO, 1990) Article 4 OPRC requires, from

the master or person having charge of the vessel, to report on all pollution-related incidents. Manned and remotely controlled vessels can comply with both conventions, but fully autonomous vessels cannot.

Construction requirements and technical conditions of ships

Convention Safety of Life at Sea (SOLAS) (IMO, 2020) in Chapter I Regulation 4b anticipates the advent of vessels with new technologies and provides maritime authorities with exemption rights from the requirements of chapters II-1, II-2, III, and IV for vessels with new technologies engaged in international voyages. This has been done to facilitate research and development. This provision leaves much discretion to the flag state, but a lack of widely recognized standards for autonomous vessels may lead to the refusal of such vessels in some places under the pretext of unproven and potentially unsafe technology. Provisions in Chapter I Regulation 5a require that the flag state conducts extensive tests before approval of new technology, to prove that it is as safe as the technologies already in use. Some hindrances for autonomous vessels can also be found in Chapter II-2: Construction, fire protection, fire detection, and fire extinction and in Chapter III: Life-saving appliances and arrangements, where the rules stipulate the presence of a crew on board.

Liability, compensation, and insurance issues

Liability in the shipping industry is based on a competent, certified crew being in charge of the vessel. In case of accidents and subsequent damage, the shipowner is liable for the action of all the parties in his service, although the master and crew are also held accountable. Liability in the shipping industry is governed by the national legal systems in the flag states. For accidents in territorial waters or on the territory of the host country, local rules are applicable. It pertains directly to manned vessels with a full crew and decision support and vessels with a reduced crew. Unmanned vessels fall into two categories. The first involves remotely controlled vessels with an operator on shore, who makes all decisions in the same way as a crew on board a manned vessel. The second category is fully autonomous vessels making decisions by themselves. In the first case, besides the shipowner, liability is placed on the remote operator similar to the master of a manned vessel, most likely under his national jurisdiction. For fully autonomous

vessels, liability lies solely on the shipowner (Danish Maritime Authority, 2017). It is unlikely to extend liability to programmers and manufacturers of ship's systems, but they are subject to national regulations. Information regarding the insurance of autonomous vessels is currently unavailable since no commercial autonomous vessels are in operation. The only existing autonomous vessels, like the Yara Birkeland, are generally built as test beds for the development of new technologies; they are not designed for international voyages (YARA, 2022). They have insurance coverage required by national regulations, but this is limited only to conducting tests.

Cybersecurity and anti-terror safeguards

Cybersecurity problems arose when the vessel began to utilize digital systems based on computer architecture. Autonomous vessels are particularly vulnerable to cyber threats, as they heavily rely upon complex computerized systems, large data transfer through satellite links, and satellite navigation. In 2017, IMO addressed the problem of cybersecurity for the first time in Resolution MSC.428(98) (IMO, 2017c), which encourages maritime administrations to address cyber risks in safety management systems. A month later, it was followed by an IMO circular MSC-FAL.1/Circ.3. (IMO, 2017b) with a list of identified shipborne systems vulnerable to cyberattacks and recommendations for cyber risk management. Up-to-date guidelines are published by the Baltic and International Maritime Council in "The Guidelines on Cyber Security Onboard Ships" version 4 (BIMCO, 2020). Today organized crime targets large shipping companies rather than single vessels. The four biggest shipping companies (APM Maersk, Mediterranean Shipping Company, COSCO, and CMA CGM) underwent cyberattacks from 2017 to extort ransom. Attacks interrupted their operations for days and even weeks (Cimpanu, 2020).

The operation of high-value autonomous vessels certainly will attract the attention of criminals. Regulatory anti-terror safeguards are provided by the SOLAS Convention (IMO, 2020) and the International Code for the Security of Ships and Port Facilities (ISPS Code) (IMO SPS, 2020). These regulations were written for manned vessels but some requirements, like the necessity to have security plans and alerts in case of a security threat, are still applicable. For unmanned vessels, more important are the technical safeguards like physically preventing access by unauthorized personnel

and effective surveillance systems. Satellite navigation systems should be protected against jamming and spoofing, in a similar way to military systems. Spoofing may result in a purposeful deviation of a vessel from its intended route with bad intentions. The jamming of the navigational satellite signal is a relatively easy task that requires simple means. Without navigational information, the vessels cannot continue their voyage. Unmanned vessels controlled from the shore and fully autonomous vessels that are remotely controlled, when required, depend solely on the exchange of large amounts of information via a satellite link. Breaking communication, or providing false information, may lead to total loss of control.

Discussion

The shipping review provided by Allianz (AGCS, 2022, p. 14) for the last decade shows a continuous decline in maritime accidents that result in the loss of a vessel. It is proof of the effectiveness of measures implemented by the international community with the purpose of increasing the safety of maritime transport. The backbone of today's shipping consists of large vessels carrying large amounts of valuable cargo or substances toxic to the environment. Any accident with such vessels may create huge material losses and unreparable environmental damage. The growing traffic density on the main shipping lanes increases the risk of an accident. Human factor was determined as the primary cause of maritime accidents (Cordon, Mestre & Walliser, 2015). The introduction of unmanned vessels, remotely controlled by highly qualified operators, or vessels with full autonomy will remove the weakest link from maritime operations. Systematically increasing crewing costs and shipowners' diminishing earnings (Clarksons, 2017) are gradually eroding the profitability of maritime shipping. The problem became more acute with the advent of the **Covid**-19 pandemic when crew costs skyrocketed.

Elimination of such costs not only improves the financial condition of the shipowners but also enables more investment in modern vessels. The shortage of competent crews has persisted for a long time. Improved work conditions on shore in developed countries have made seaman's jobs uncompetitive. Particularly the acute shortage of management-level officers with a technical background. Significant pay rises may mitigate this problem, but shipowners' tight budgets may not withstand it. Considering all the above, the introduction of autonomous

vessels seems to be the correct response. Advances in technology allowed the building of a large-scale 80 meters long, fully functioning model of a fully autonomous vessel (YARA, 2022), which will provide valuable data for future projects. This development confirmed that necessary technologies are available today. Special attention needs to be given to rules that govern maritime shipping. Analysis of the regulatory barriers by the Danish Maritime Authority (Danish Maritime Authority, 2017) found several shortcomings of the existing regulations, which need to be rectified at either international or national levels by governments of coastal states before the use of autonomous vessels becomes feasible. IMO conducted a regulatory scoping exercise (IMO, 2022) and indicated the regulations to be amended; they also showed the necessity to create new ones. The conducted IMO exercise became a basis for work on future MASS codes. Satellite communication and navigation technologies, in use today, will require a hardening against unfriendly acts to prevent the hijacking or disabling of unmanned vessels, which could be targeted for their valuable cargo. Future projects need to account for very effective means that prevent unauthorized access.

Conclusions

The introduction of autonomous vessels is a viable solution to problems that bother maritime transport. The human elements are the largest factor accountable for maritime accidents, the elimination of which may significantly improve the safety of naval transportation. Autonomous vessels should resolve problems with excessively high crewing costs and a short supply of competent crews, mainly officers. Such problems for shipowners are getting worse with time. The launch of the first large-scale, fully functional model of an autonomous vessel has proved the concept of unmanned vessels and the availability of the necessary technologies. Regulatory barriers at international and national levels require amendments to the existing rules and the creation of new ones. When introduced, an autonomous vessel will require an improvement of the existing communication and navigation technologies to make them more resilient to unfriendly acts.

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Impact of psychological components of human factors on the probability of committing an error during ship handling in restricted waters

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Abstract

The paper presents a new approach to the evaluation of human factor (HF) influence on the risk of maritime accidents. This approach is based on a formal human–ship–environment system definition including the relationships between humans, technology, environment, and organization. Social and organizational factors have already been included in the International Maritime Organization regulations; however, the individual factors still need investigation. A combination of psychological studies and technical operations of sea-going ships has given a huge opportunity to use HF assessment in rule-making processes. The main scientific goal of the research presented in the paper was the development of a method to assess the influence of HF on the risk of maneuvering accidents in restricted waters. This method is based on research within the area of technical ship operation and the results of the psychological profile of operators. The proposed model is based on a quantitative HF model developed by an authorized psychologist comprising personality traits, vulnerability to stress, and risk approach. The investigations were carried out with a group of 32 experienced ship masters performing a complex maneuvering task on the Full Mission Ship Handling Simulator. The multidimensional dependencies between variables of the psychological profile and the risk of an accident resulting from maneuvering errors were implemented into the Sugeno fuzzy model. The developed model allows risk assessment to be conducted that depends on the selected personality profile features. These features can be measured using psychological questionnaires, and then the risk of an accident due to maneuvering error can be calculated for a captain or marine pilot in order to improve human resource management.

Introduction

The development of ISM (negligence) and STCW (poor training) has decreased the accident rate, but only half of all human factor (HF) components have been found and defined. Therefore, we need to look further to define these components and find remedies. The article shows a different approach to the topic. Research on HF from the aspect of psychology is being carried out around the world, mainly in air transport, but not much of this research has been

carried out in maritime transport (Hejmlich, 2014; Havold, 2015; Hejmlich & Abramowicz-Gerigk, 2017; Makarowski et al., 2017; Hejmlich, 2018). This paper is a description of such research performed by a doctoral student on a ship maneuvering simulator in conjunction with the use of psychological tests to determine the psychological profile of ship captains and port pilots.

In decision theory, risk relates to a situation in which the selection of a given decision entails the possibility of consequences occurring with a known

probability of occurrence for each possibility (Battacharya, 2012).

Risk taking, therefore, means knowingly accepting a potential loss relaying on mathematical expectation.

$$\text{Risk} = \text{probability} \times \text{consequences}$$

Risk taking, therefore, is a compromise between safety and profit.

However, should we consider a compromise in terms of safety?

Research has shown that human error contributes to (Berg, 2013):

- 84–88% of tanker accidents,
- 79% of the grounding of tugs,
- 89–96% of collisions,
- 75% of allision,
- 75% of fires and explosions.

Statistics show that there are around 100,000 ships in the world and more than 2000–2500 marine accidents per year. This means the probability of each ship being involved in an accident is 0.025.

The probability of HF resulting in an accident is 0.02.

It is tempting to accept certain consequences due to a low probability, but the probability of 0.02 for heavy accidents (10% of all accidents) may mean a loss of 200 human lives per year per 2,000,000 people working at sea. This makes 10^{-4} per year, which is far away from the ALARP level of 10^{-6} for individual risk (Chauvin, 2011).

Should we control the risk by minimizing losses or by minimizing the probability of unwanted events?

HF with partly identified components are presented in Figure 1.

The Reason's model adopted for HF components is presented in Figure 2.

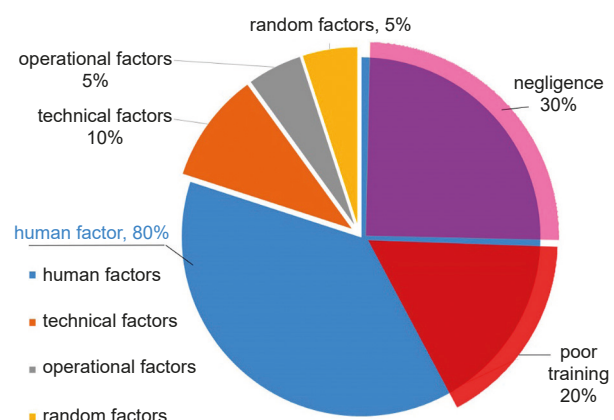


Figure 1. Human factors with partly identified components (Berg, 2013; Mokhtari & Khodadadi-Didani, 2013)

Research method

The main scientific goal of the research was to identify and assess more components of HF.

The research consisted of two parts, which were combined in the model.

- Part one: Survey of the psychological profile of each participant (Brzeziński, 1980).
- Part two: Test on Full Mission Bridge Simulator.

Survey of psychological profile

Psychological questionnaires were presented to participants:

- Sense of Stress Questionnaire (KPS) (Plopa & Makarowski, 2010).
- Stimulation and Instrumental Risk Questionnaire (RS&RI) (Makarowski, 2012).
- NEO-FFI Questionnaire (Big Five Personality Traits) (Costa & McCrae, 2003).

A qualified psychologist decoded the questionnaires and presented the results as numerical scores.

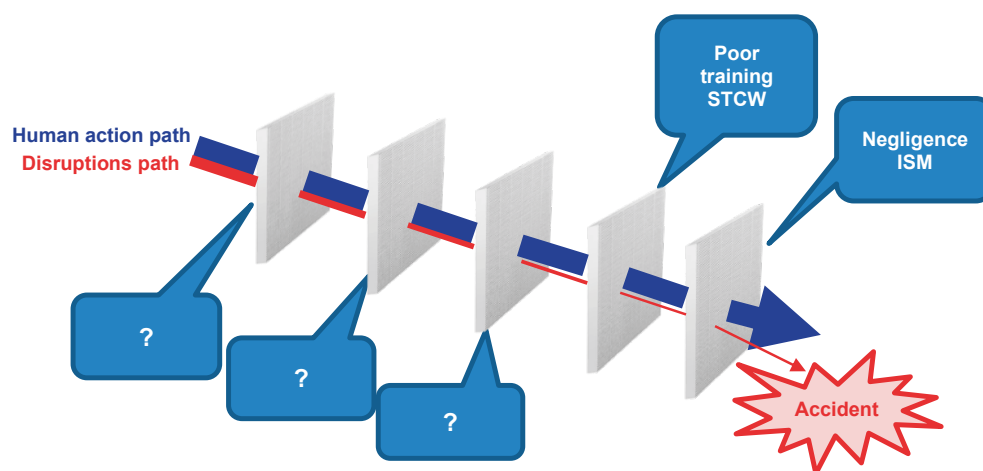


Figure 2. Reason's model adopted for human factor components

Table 1. Questionnaire scores

#	Stimulating Risk (SR)	Instrumental Risk (IR)	Emotional Tension (ET)	Internal Stress	Intrapsychic Stress (IS)
1	4	14	12	8	13
2	10	14	19	13	14
3	4	15	7	7	7
4	10	14	15	16	12
5	15	6	22	15	17
6	4	12	7	7	9
7	13	15	14	11	9
8	6	12	20	17	19
..	..	..	..	..	..
32	14	10	24	19	20

The questionnaire scores are presented in Table 1.

The most promising Pearson's correlation with committed errors numbers was found for two groups, representing risk approach attitude and stress level.

The scores for grouped components SR – IR and ET + IS are presented in Table 2.

Test on Full Mission Bridge Simulator

A simulator test was performed to run the ship all the way from a sea buoy to the berthing dock.

Errors during the passage were counted and rated. This was a time-pressure, stress-triggering situation. One area was particularly interesting: the canal bent where a strong bank effect occurs for speeds higher than 8 knots. Shortly before this bent, operators

Table 2. Scores for grouped components SR – IR and ET + IS

SR – IR	ET + IS
-10	25
-4	33
-11	14
-4	27
9	39
-8	16
-2	23
-6	39
..	..
4	44

received a message about berthing scheduled in a tight time window. A screenshot from the simulator simulation showing the control point is presented in Figure 3.

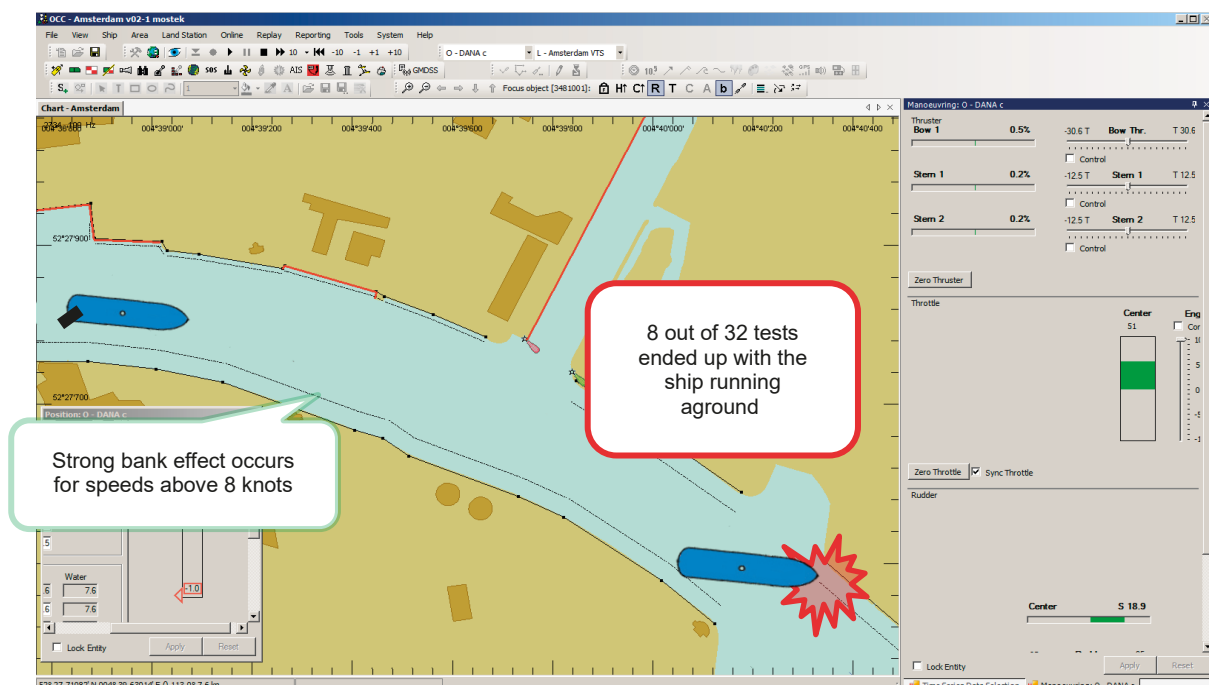
As a result, 8 out of 32 experienced captains and pilots committed a fatal error and failed to stay in the canal range and finally ran the ship aground.

Results processing and discussion

Psychological survey scores were compared with the simulator performance test for each participant in both aspects: risk approach attitude and stresses level.

Figure 4 shows the influence of risk approach attitude on the simulator results.

The participants with stimulated risk scores higher than instrumental risk were rated: 5 failed and


Figure 3. Screenshot from the simulator showing the control point

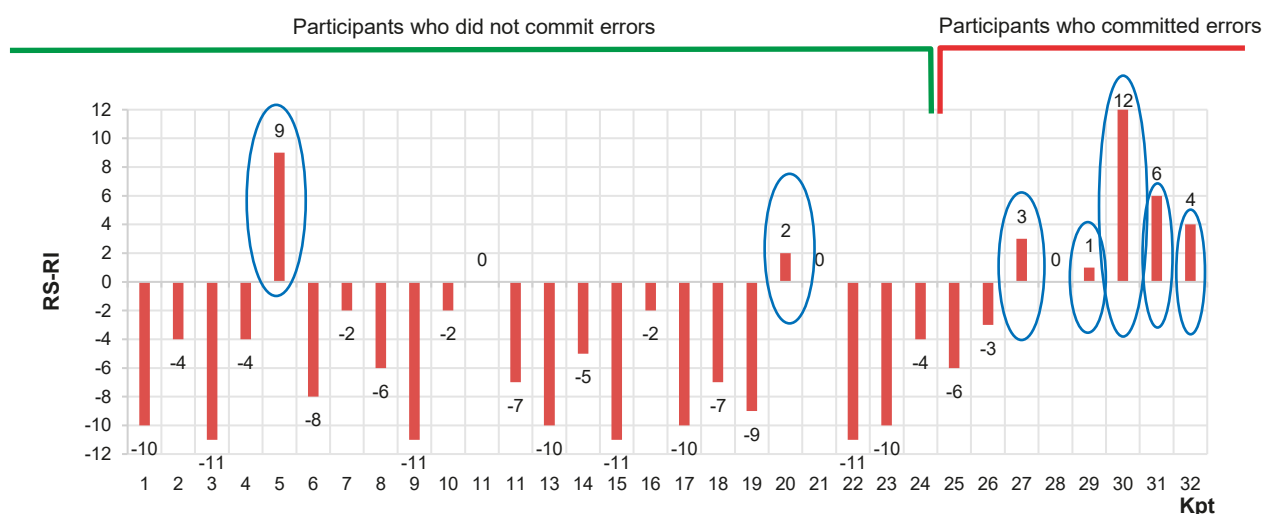


Figure 4. Diagram showing the influence of risk approach attitude on the simulator results

2 passed the simulator test. Participants with higher instrumental risk scores were rated: 1 failed and 21 passed. Participants with equal IR and SR were rated: 1 failed and 2 passed.

The total probability of having a command operator with a higher SR score (a higher probability of failure) computed with the Bayesian network was 0.11 (Figure 5).

Figure 6 shows the influence of stress level on the simulator results.

Participants with elevated stress levels above 40 were rated 4:1 fails to successes.

Respectively, the previous calculation using the Bayesian network found a total probability of a having more stressed operator was 0.18.

Additionally, both features created a higher probability of failure for 3 out of 32 participants, and all 3 failed the simulator test (Figure 7).

This experiment allowed the identification of differences in performance in aspects of various psychological profiles. It identified two components



Figure 5. Bayesian network computing the total probability of higher SR scores in a population (MSBNs v.1.4.2, 2017)

with a strong impact on safe performance during routine maneuvers. Risk approach attitude gave a probability of errors at 0.11, and stress level gave a probability of errors at 0.17. On the basis of the above results, the Reason's model (Figure 8) was supplemented with unknown "filters".

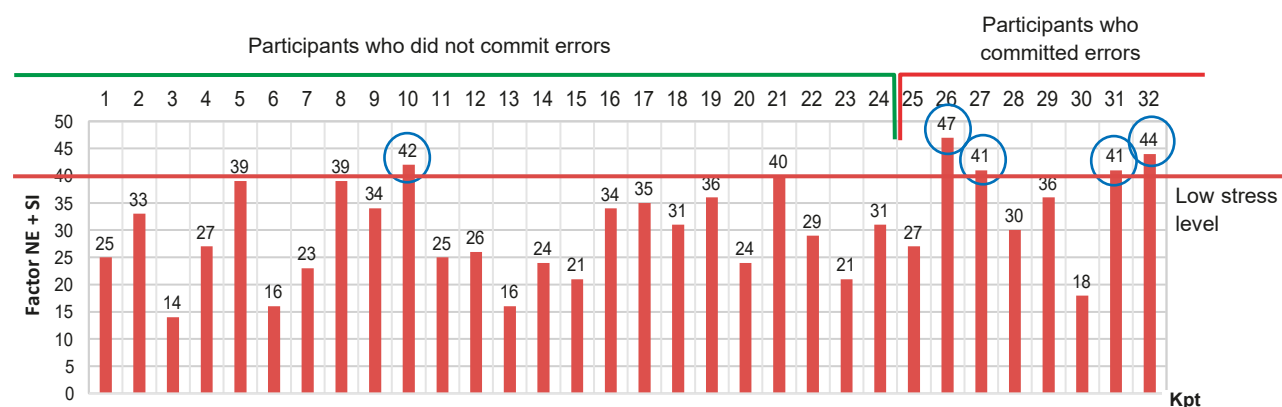


Figure 6. Diagram showing the influence of stress level on the simulator results

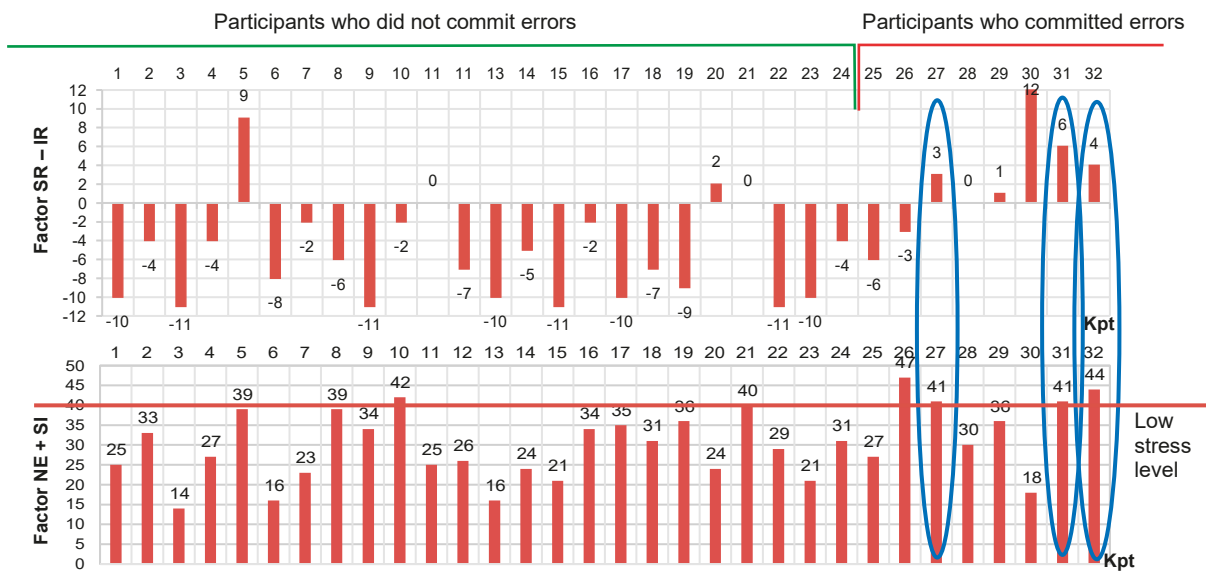


Figure 7. Diagram showing the influence of stresses level and risk approach on the simulator results

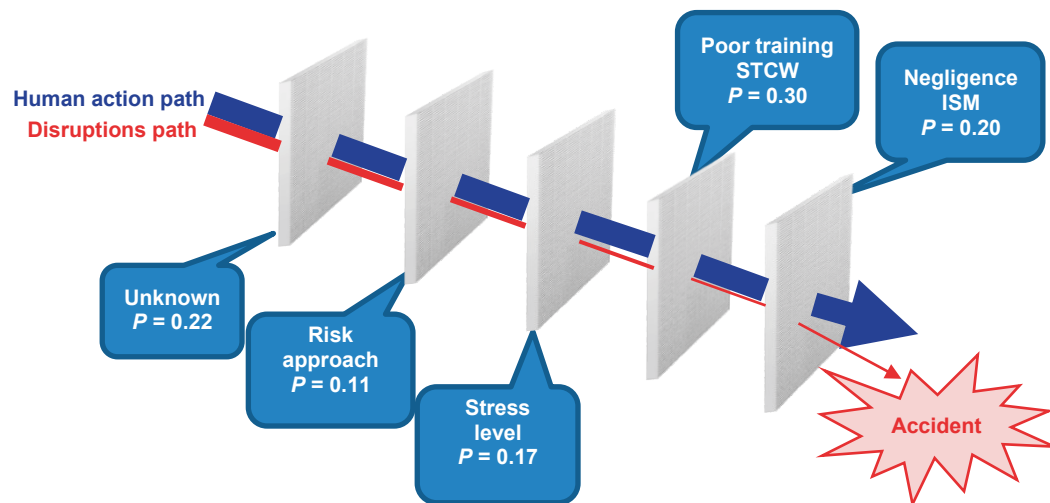


Figure 8. Reason's model supplemented with new filters

Mathematical model of the results

Five variables presented in Figure 8 were taken as input values for the Sugeno fuzzy model created in the computing environment (MatLab, 2022) (Figure 9).

The Sugeno model is a fuzzy neural network, which allows knowledge to be expressed by natural language in an easy way. It can calculate the outputs for input data out of the range initially foreseen.

The model is very stable, and small input differences generate small differences at the exit (with an appropriate structure of membership functions assignment).

The Sugeno model interface is intuitive and, thus, easy to operate.

Entering of input data is executed by moving the sliders or manual typing of data numbers in the left, lower window. Figure 10 shows the model tuned for the situation with the probability of an accident at 0.025.

Modeling of the psychological component of HF began with a reduction of risk approach attitude. In practice, this means selecting operators with an instrumental risk higher than the stimulating risk. The probability of an accident decreases to 0.020 (Figure 11).

Consequently, a decrease of stress level by a probability value of 0.01 is presented in Table 3.

The Sugeno model interface showing the results after stress level reduction by 30% is presented in Figure 12.

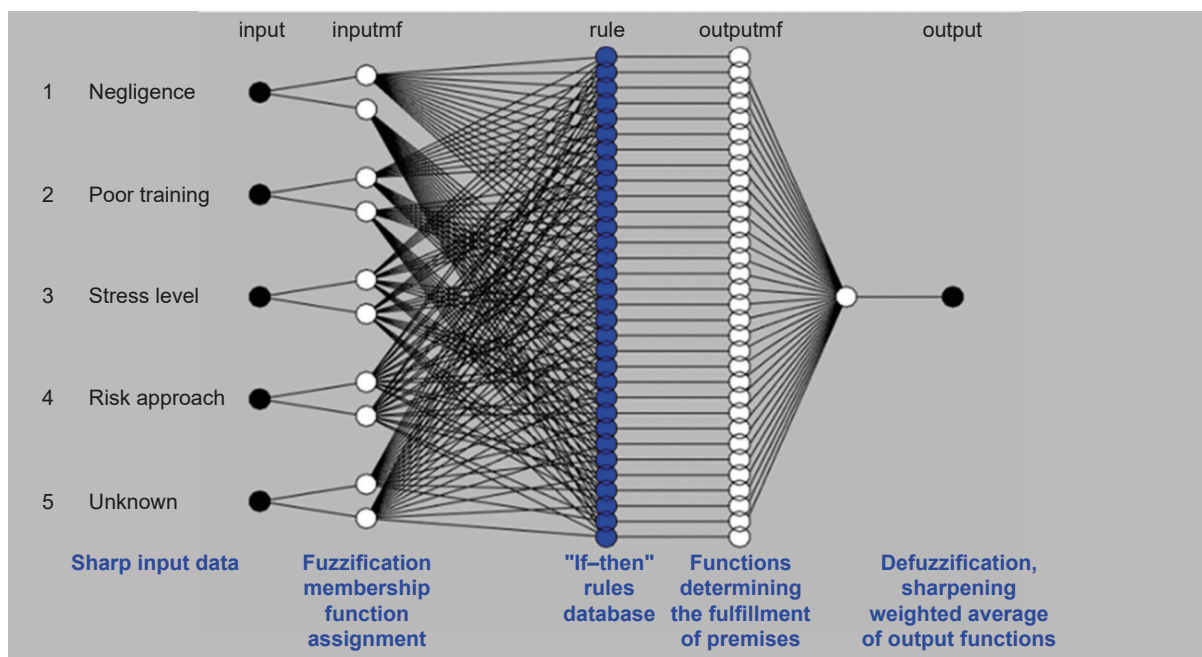


Figure 9. Sugeno fuzzy neural network model structure



Figure 10. Sugeno Model interface showing the present situation

Table 3. Results of risk approach and stress level modeling by the Sugeno model (C – column shows the present situation)

A	B	C	D	E	F	G	H	I
Risk approach max 0.17	0.17	0.17	0.00	0.0	0.0	0.0	0.0	0.0
Stress level max 0.11	0.11	0.11	0.11	0.10	0.09	0.08	0.07	0.06
Negligence max 0.30	0.30	0.164	0.164	0.164	0.164	0.164	0.164	0.164
Poor training max 0.20	0.20	0.126	0.126	0.126	0.126	0.126	0.126	0.126
Unknown max 0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22
Probability max 1	1.00	0.024	0.02	0.0165	0.0128	0.009	0.005	0.002

Although the reduction of risk approach attitude is self-explanatory, the reduction of stress level needs

further action. Table 3 shows how a reduction of stress level decreases the probability of an accident.

Risk approach reduction

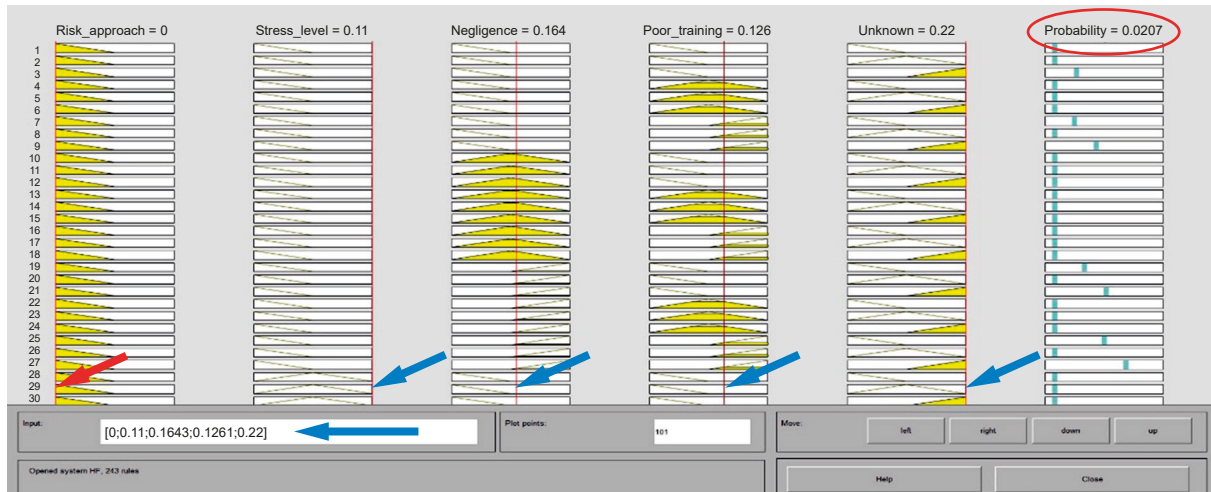


Figure 11. Sugeno model interface showing the results after stimulation risk has been eliminated (Table 3 column D)

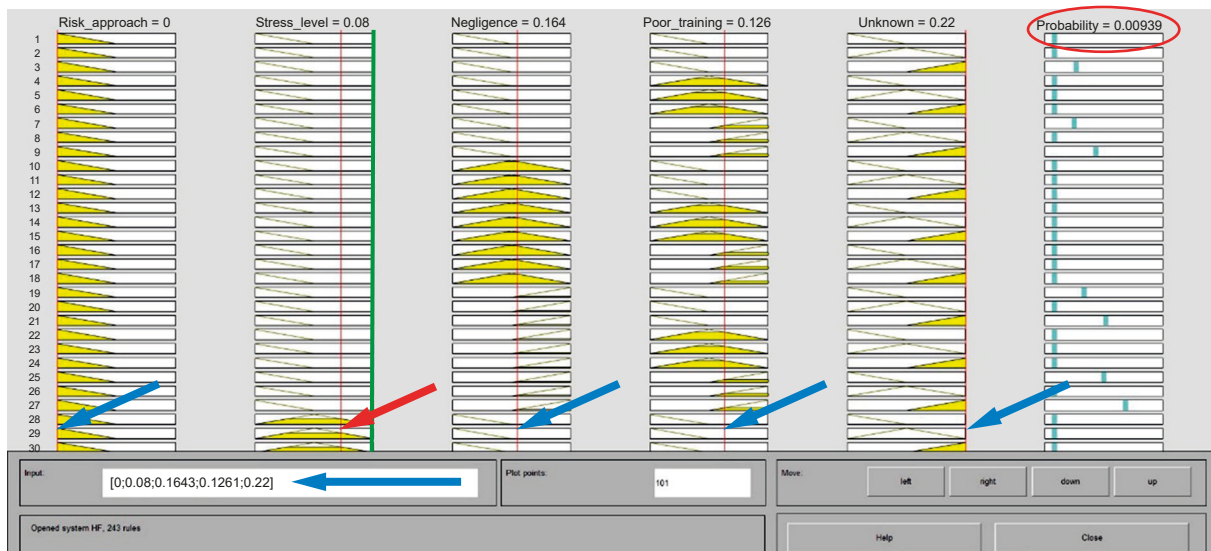


Figure 12. Sugeno model interface showing the results after stress level reduction by 30% (Table 3 column G)

Table 4. Stressors list

1. Ship safety	13. Safety of crew
2. Crew conflicts	14. Limited possibilities for relaxation
3. Incompetence of the ship owner's office employees	15. Office-ship conflicts
4. Continuous port inspections	16. Divorce
5. Wariness about jobs	17. Storm
6. Constant emergency	18. Frequency of maneuvers
7. Finances	19. Night work
8. No Internet on ships	20. Death of a loved one
9. Charterer pressure	21. Overload with office work
10. No rest in port	22. Ship-owner's pressure
11. Separation from family	23. Family situation
12. Safety of family	24. Too few crew members

During this research, participants were asked to reveal what stresses them the most at work Hejmlich, A. (Hejmlich, 2016), and a list of stressors was established (Table 4). Stressors are the factors that may trigger stress development. Stressors bolded on the list are rated as organizational factors.

Thus, stress could be easily reduced or eliminated at any level of operations on the ship, company, flag state, or IMO level.

Conclusions

The following conclusions can be drawn from the presented research:

1. Defining the components of HF allows for effective control of the probability of making an error.
2. Nine out of a hundred captains and pilots have a high probability of making an error. Thus, unpopular selection is necessary for operators in accordance with their psycho-physical abilities.
3. Reduction of stressors listed in Table 4 by legal and administrative regulations would decrease the stress triggering factors, stress level, and accident probability.
4. The proposed method would be based on a few questions – a questionnaire taken by candidates to define their psychological profile in order to assign individuals with a high probability of error-making characteristics to lower-risk tasks.
5. The method allows the “risk owner” to make a risk assessment depending on expected losses. The costs of individual and material losses are commonly known.

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Free running ship model tests of interaction between a moored ship and a passing ship

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Keywords: interaction forces, safe mooring, fuzzy model, neural network, numerical modeling, bypassing ship

JEL Classification: C45, C93, L91, R41

Abstract

For many reasons, ship model interaction tests are performed in experimental towing tanks. This paper presents research on the hydrodynamic forces acting on a ship tied up at the solid berth, which is produced by other ships passing by using free-running ship models with much larger dimensions than those used in towing tanks. A passing ship model was controlled by a human operator – an experienced master. This enabled a study of the influence of the interaction impact on the course of the maneuver. The research was carried out at the Ship Handling Research and Training Centre in Ilawa. The ship model was moored alongside and equipped with multi-directional force sensors linking the ship model with a solid berth. Forces were measured as a function of the passing ship speed, side distance between both ships, ship sizes, and depth-to-draft ratio (H/T). Forces were measured in two planes: the longitudinal (surge) and the transversal (sway). A numerical database was processed and ordered according to the variables. The fuzzy model was created within a “Matlab” computing environment using a Sugeno-type self-learning neuron network model. The proposed Sugeno model was evaluated with other methods presented by Flory (2002), Seelig (2001), and PASS-MOOR by Wang (1975). The ultimate goal of this study was to simplify the method of predictive calculations for adjusting speed and distance when passing by the moored ship, which ensures compliance with safe port mooring requirements.

Introduction

It is commonly known that when a moored ship is passed there are hydrodynamic forces such as surge forces F_x , sway forces F_y as well as yaw moments M acting upon it. These forces trigger movements of the moored ship that causes tensions on the mooring lines, which can lead to the rupture of the mooring ropes. If the passing ship sails at high speed and the distance between the ships is small, and the ships

have a minimum clearance under the keel, the berthing loads can be considerable, and in the case of exceeding their admissible values, damage can occur to the moored ship, its mooring equipment, the dock, and the fenders (Vasudevan & Seeninaidu, 2017). There are many descriptions of serious accidents resulting from this interaction; despite this, there are no guidelines on how these effects should be assessed and how to include them in the designs of mooring systems and operational practice (Pinkster, 2011).

Literature review

Figure 1 shows the hydrodynamic forces that act upon a moored ship when it is passed by another vessel.

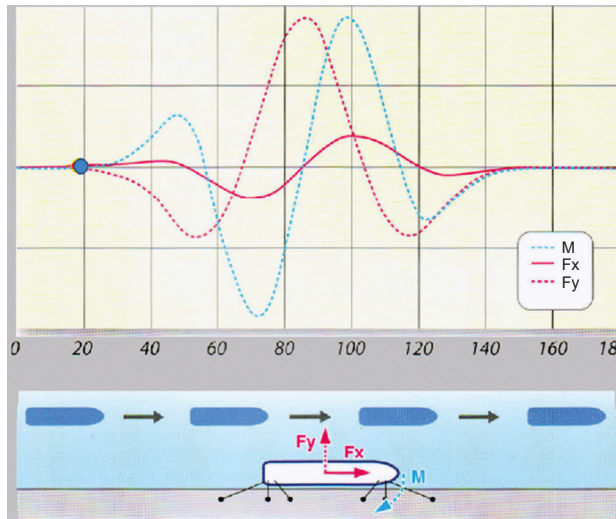


Figure 1. Forces acting on a moored ship

These forces can be calculated using the formulas:

$$F_x = C_x \cdot 0.5 \cdot \rho \cdot T \cdot L \cdot V^2 \quad (1)$$

$$F_y = C_y \cdot 0.5 \cdot \rho \cdot T \cdot L \cdot V^2 \quad (2)$$

where C_x represents the coefficient for the peak surge force, C_y denotes the coefficient for the peak sway force, ρ signifies the density of water, T is the draft of the moored ship, L is the length of the moored ship, and V is the speed of the passing ship. Both formulas contain the parameters of the moored ship and the speed of the passing ship. The other variables are hidden within the coefficients C_x and C_y . Most researchers focus on determining coefficients C_x and C_y .

Wang (Wang, 1975) determined the forces and moments occurring as a result of a ship passing by; he worked out an analytical method. He calculated the forces and moments as a function of time for an infinite depth of water. He also used correction coefficients to consider the effect of shallow water. Seeling (Seeling, 2001) used the figures found for deep water from Wang (Wang, 1975). Here, in the case of shallow water, correction coefficients were formulated with the use of the reanalyzed results of the test in a scaled model carried out previously. For estimating moments and peak forces, he created an Excel calculation sheet. Flory (Flory, 2002) worked out simple formulas to estimate forces and moments that arise due to the passing of ships with the use

of a few published results and models. In his calculations, he used scale factors according to Froude's Model Law and considered the coefficient of clearance under the keel. Kriebel (Kriebel, 2005) carried out a few laboratory tests in scaled models and formulated simple empirical formulas for calculating forces and moments. Apart from this, he also studied Seeling's and Flory's methods and compared them with the experimental data he obtained. Based on his research, he re-derived Seeling's correction coefficients and introduced a set of new empirical formulas for the correction coefficients. All the methods discussed above consider Bernoulli's suction effect to be the main cause of the forces and moments that arise.

The main parameters that affect the system in all the above-mentioned papers are the speed of a passing ship, the separation distance, the displacement of the ship, and the water depth. The courses of the forces and moments are related to the relative variability of the position of the passing vessel against the moored vessel. The effect of the passing vessel begins roughly at a distance twice longer than the length of the ship (Flory, 2001). Variability at every time step takes place according to a similar pattern in all cases. This research aims to simplify the predictive calculation method to enable an adjustment of the speed and distance while passing along a moored vessel, so that compliance with safe mooring requirements at the harbor is maintained.

Description of model tests

This paper presents research on the hydrodynamic forces that act on a moored vessel at the permanent berth, which are produced by another vessel passing the former one in a parallel direction. The models used for the research were free-running ship models with far larger sizes than those used in towing tanks. In addition, the passing vessel model was controlled by a person – an experienced master.

The variables in the tests contained: the speed of the passing vessel, the passing distance between the ships, the sizes of vessels, and the ratio of depth-to-draft (H/T). Forces were measured in two planes: longitudinal (surge) and transversal (sway). A further step was used to determine the peak values for surge and sway forces. The numeric database, which was formed as a result, was processed and ordered. The database was implemented onto the fuzzy logic panel of the computing environment Matlab 2021 and a self-learning neural network of Sugeno type was created.

Test configuration and sign convention

All the tests use the parallel configuration indicated in Figure 1, in which the passing ships moves parallel to, and in the same direction as, the moored ship. A clockwise coordinate system has been adopted, the origin ($x = 0, y = 0$) of which is located amidships the moored vessel. The sign convention follows the right-hand rule: $+x$ – the bow, $+y$ – portside.

Facility, test rigs, and ship models

The research was carried out at the Ship Handling Research and Training Centre in Ilawa in the area presented in Figure 2.

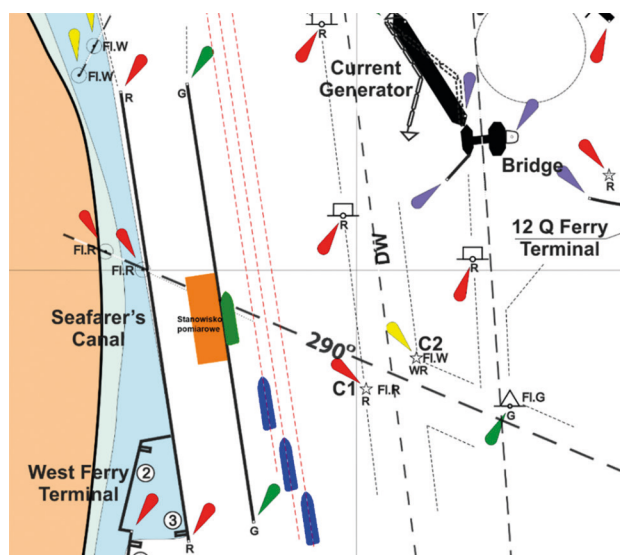


Figure 2. Test area at the Ship Handling Research and Training Centre in Ilawa

The moored vessel model was equipped with multi-directional force sensors, which at the same time linked the model with the berth. The exact arrangement of the sensors is provided in Figures 3 and 4, and the dimensions of the moored vessel can be found in Table 1.



Figure 3. A measuring station was installed at the deep-water harbor

Table 1. Parameters of the moored ship

Item	Symbol	Moored ship	Moored ship model
Length overall	L_{OA} [m]	218.85	9.17
Beam	B [m]	30.50	1.26
Draft	T [m]	12.09	0.51

The computer measured the recorded data from the measuring sensors for the forces F_x and F_y , and the speed of the vessel in motion, connection scheme shown in Figure 5. On the basis of the GPS position, it computed dynamic longitudinal and transversal distances between the vessels.

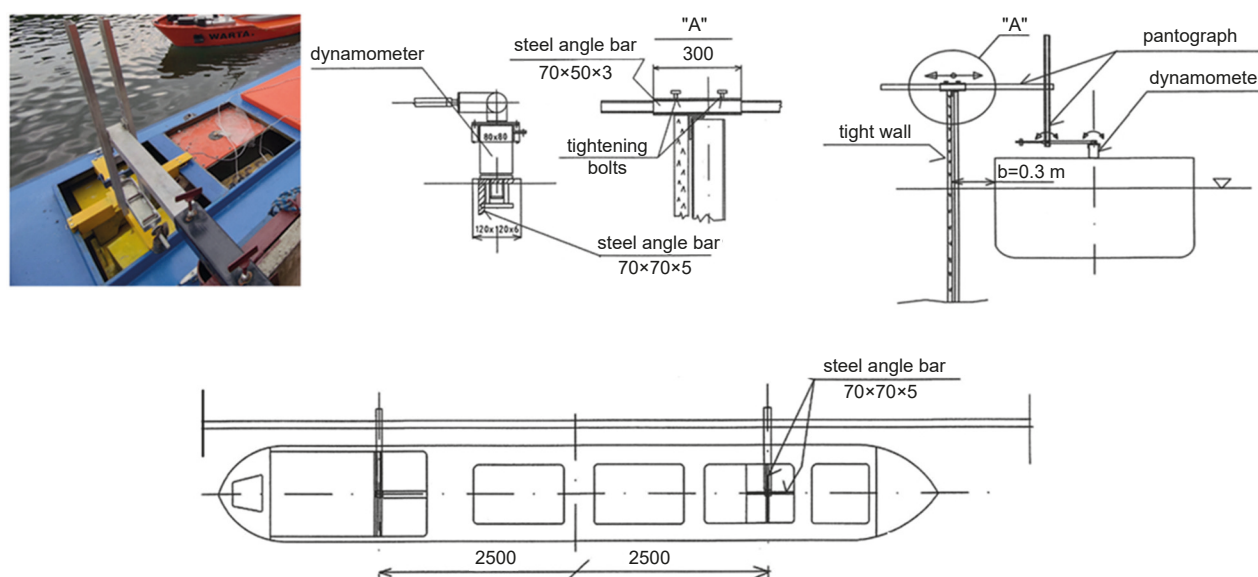


Figure 4. Depiction and dimensions of the moored ship

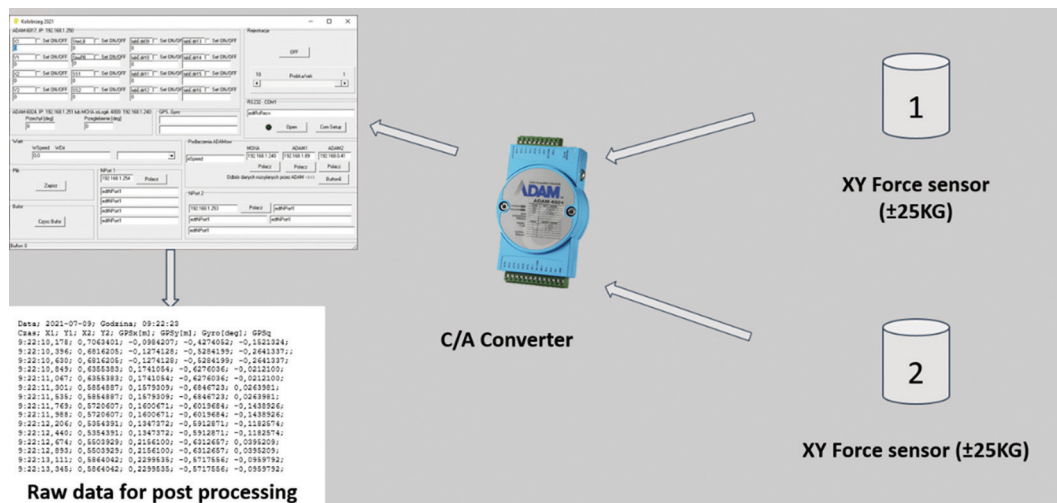


Figure 5. A measuring system on the moored ship model

Item	Symbol	Ship	Model
Length overall	L_{OA}	292.93 m	12.21 m
Length between perpendiculars	L_{BP}	278.00 m	11.58 m
Beam	B	48.00 m	2.00 m
Draft	T	15.33 m	0.64 m
Max. speed	V	15.5 kn	3.2 kn
Displacement	Δ	176 967 T	12.49 T
Block coefficient	C_B	0.844	0.844
Rudder area ratio	$A_P/(L_{BP} \times T)$	1.76%	1.76%

Other information:

- Main engine: Diesel, optional Turbine;
- Single 5-bladed right-handed propeller;
- Conventional rudder;
- 2 anchors + 2 cables 12 shackles each;
- Tug simulator – two 55 tons bollard pull tugs working on a line are available;
- GPS;
- Scale 1:24.



Figure 6. Model No. 1 – WARTA (LCC)

Item	Symbol	Ship	Model
Length overall	L_{OA}	227.76 m	9.49 m
Length between perpendiculars	L_{BP}	217.00 m	9.04 m
Beam	B	32.10 m	1.34 m
Draft	T	12.50 m	0.52 m
Max. speed	V	16.0 kn	3.1 kn
Displacement	Δ	75 550 T	5.46 T
Deadweight	DWT	66 200 T	n.a.
Block coefficient	C_B	0.86	0.86
Rudder area ratio	$A_P/(L \times T)$	1.86%	1.86%

Other information:

- Main engine: Diesel;
- Single 4-bladed right-handed propeller;
- 2 anchors + 2 cables 12 shackles each;
- Bow thruster;
- Tug simulator. Two 40 tons bollard pull tugs are available;
- Rudder: conventional (35° of max. deflection angle), optional single Schilling rudder (70° of max. deflection angle) or Becker rudder (55° of max. deflection angle);
- Scale 1:24.



Figure 7. Model No. 2 – BLACK LADY (panamax bulk carrier)

Two test models for the two vessels of different sizes were used. These are scaled replicas of the particular vessels at full scale. The parameters of the vessel models are provided within the tables in Figures 6 and 7.

Model vessels were equipped with the following:

- GPS Leica Viva GS10 with reference station. Accuracy of position: ± 0.01 m;
- Anschütz Gyro Compass System Standard 22. Accuracy of HDG $< 0.4^\circ$.

Test conditions and data analysis

Four key variables were identified during the measurements:

- the ship size ratio (DWT_1/DWT_0) – defined as the deadweight of the passing vessel in relation to that of the moored vessel;
- the depth-to-draft ratio (H/T) – defined as the draft of the moored ship relative to the water depth;
- the separation distance (s [m]) – the side distance;
- the moving ship velocity (V [m/s]).

Ship size ratios included only two values:

- 1.15 – the size of the passing vessel was the same as the size of the moored vessel;
- 2.71 – the size of the passing vessel was smaller than the size of the moored vessel.

Water depths in the tests were selected to obtain two sizes for the *depth-to-draft ratio*: 1.20 (for shallow water) and 2.0 (for deep water).

Separation ratios were successively: 30.24 m, 60.48 m, 75.60 m, and 90.72 m, that is approximately:

Table 2. Tabulation of the test conditions and results for deep water and same-size ships

DWT_1/DWT_0	H/T	s [m]	v [m/s]	$F_{x\min}$ [T]	$F_{x\max}$ [T]	$F_{y\min}$ [T]	$F_{y\max}$ [T]
1.15	2.00	30.24	2.73	-22.86	-54.85	21.84	28.66
1.15	2.00	30.24	5.35	-68.47	-108.46	41.55	70.01
1.15	2.00	30.24	5.45	-97.07	-145.43	58.68	107.91
1.15	2.00	30.24	6.53	-149.97	-202.78	98.24	138.04
1.15	2.00	30.24	6.74	-157.15	-249.78	106.42	161.44
1.15	2.00	60.48	2.26	-5.87	-25.40	9.93	17.49
1.15	2.00	60.48	3.70	-22.14	-31.54	12.80	19.15
1.15	2.00	60.48	5.50	-39.96	-71.27	32.36	32.97
1.15	2.00	60.48	5.55	-50.16	-81.48	40.45	59.08
1.15	2.00	60.48	7.20	-86.00	-129.72	78.52	99.52
1.15	2.00	90.72	2.88	-8.34	-43.29	24.31	31.40
1.15	2.00	90.72	3.91	-17.82	-70.77	12.54	35.67
1.15	2.00	90.72	4.83	-29.03	-35.94	24.79	28.45
1.15	2.00	90.72	5.76	-32.96	-52.38	33.94	40.74
1.15	2.00	90.72	6.89	-55.24	-71.81	42.37	52.52

1B, 2B, 2.5B, and 3B (B is the beam of a moored ship). *Moving ship velocity* ranged from approximately 4 kn to 20 kn in the following passes. For the above-mentioned parameters, combinations of passes were carried out during which the following were measured: the surge force and sway force. Then, the peak values for these forces were extracted: $F_{x\min}$, $F_{x\max}$, $F_{y\min}$, and $F_{y\max}$. Selected examples of peak force values, for particular variables, are presented in Tables 2–4.

Table 3. Tabulation of the test conditions and results for deep water and LCC vs. small ship

DWT_1/DWT_0	H/T	s [m]	v [m/s]	$F_{x\min}$ [T]	$F_{x\max}$ [T]	$F_{y\min}$ [T]	$F_{y\max}$ [T]
2.71	2.00	30.24	2.93	-33.10	-62.52	35.90	44.04
2.71	2.00	30.24	3.09	-43.13	-74.05	43.56	64.52
2.71	2.00	30.24	3.65	-59.23	-110.28	78.16	83.95
2.71	2.00	30.24	4.27	-80.90	-121.04	89.22	93.52
2.71	2.00	30.24	5.04	-124.52	-162.60	145.87	124.13
2.71	2.00	60.48	2.52	-17.64	-29.81	21.53	39.45
2.71	2.00	60.48	3.50	-36.32	-62.23	42.36	37.99
2.71	2.00	60.48	4.22	-60.10	-80.36	59.54	58.07
2.71	2.00	60.48	4.99	-80.45	-113.43	71.32	83.59
2.71	2.00	60.48	6.22	-112.12	-183.76	140.52	171.97
2.71	2.00	90.72	2.26	-13.93	-19.26	11.41	23.78
2.71	2.00	90.72	3.14	-28.51	-26.41	22.47	33.85
2.71	2.00	90.72	4.32	-34.80	-59.98	36.42	29.33
2.71	2.00	90.72	4.94	-52.73	-78.86	53.32	36.94
2.71	2.00	90.72	6.17	-79.25	-132.18	90.43	59.61

Table 4. Tabulation of the test conditions and results for shallow water and same-size ships

DWT_1/DWT_0	H/T	s [m]	v [m/s]	$F_{x\min}$ [T]	$F_{x\max}$ [T]	$F_{y\min}$ [T]	$F_{y\max}$ [T]
1.15	1.20	30.24	3.87	-2.83	-40.57	14.86	49.65
1.15	1.20	30.24	4.36	-5.51	-65.50	-5.51	-65.50
1.15	1.20	30.24	6.22	-2.87	-134.33	44.46	82.10
1.15	1.20	30.24	6.95	1.55	-134.32	67.24	101.18
1.15	1.20	30.24	9.11	-8.07	-271.73	116.19	232.56
1.15	1.20	60.48	3.87	-0.85	-32.48	11.00	27.58
1.15	1.20	60.48	6.02	-1.34	-60.88	24.42	60.97
1.15	1.20	60.48	7.05	2.68	-100.14	38.53	71.84
1.15	1.20	60.48	9.11	0.43	-190.41	62.88	186.22
1.15	1.20	60.48	11.17	-9.71	-244.82	114.18	238.34
1.15	1.20	75.60	3.23	-2.17	-30.64	7.46	20.48
1.15	1.20	75.60	5.63	-2.70	-59.68	21.48	56.48
1.15	1.20	75.60	6.32	-4.34	-55.76	25.73	57.51
1.15	1.20	75.60	6.90	-0.47	-90.29	31.17	62.49
1.15	1.20	75.60	8.08	-0.04	-110.35	34.94	62.24
1.15	1.20	75.60	9.60	3.77	-156.28	62.09	101.54

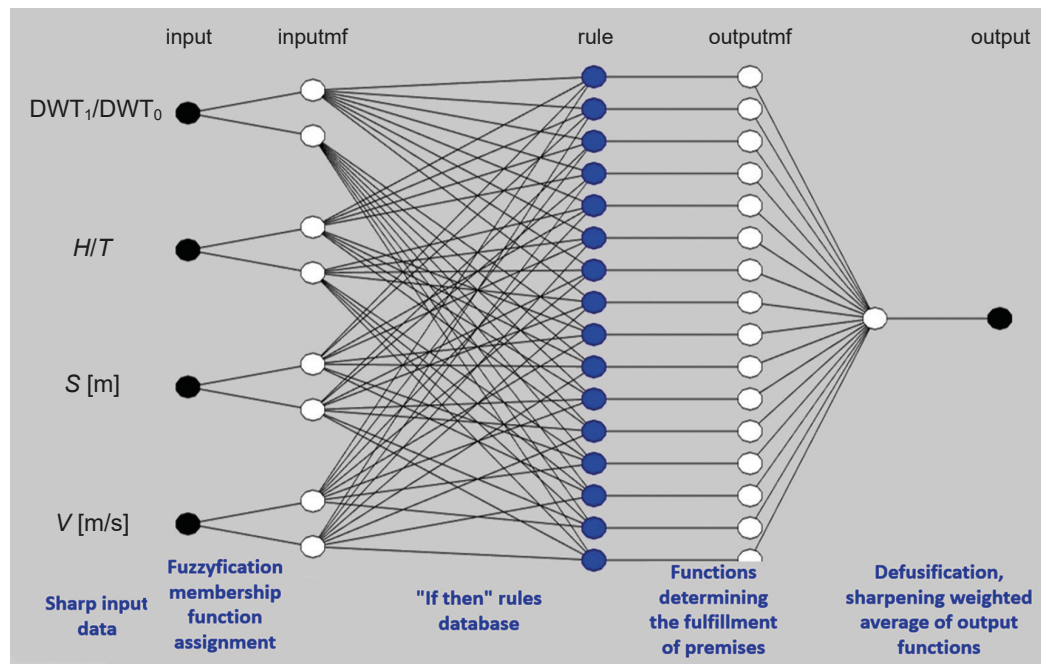
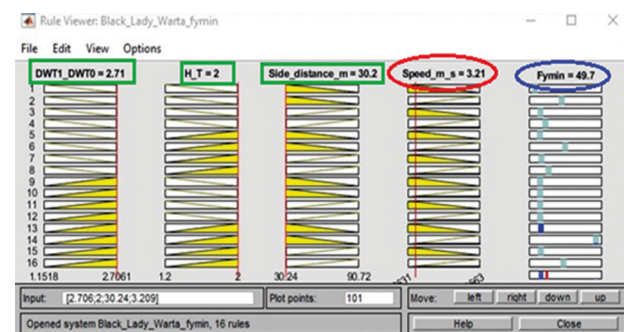
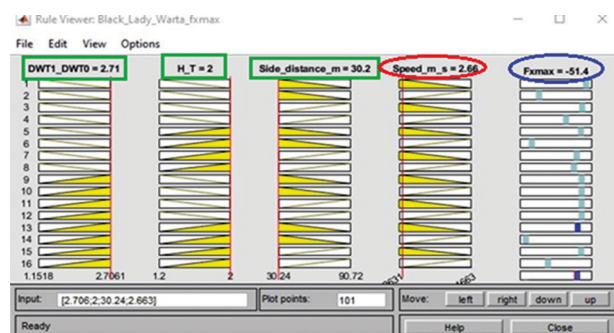
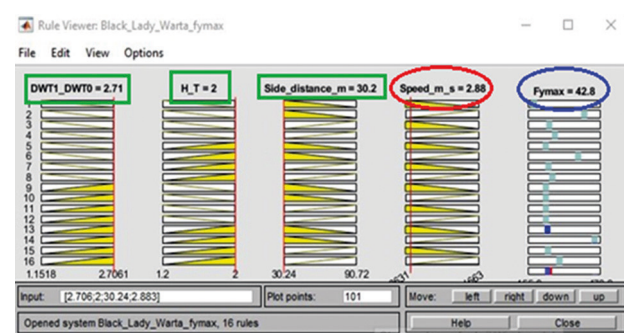


Figure 8. Screenshot of SUGENO model structure

The variables and force peaks described above constituted the input database for the Matlab (Matlab R2021b) computing environment (the "if-then" rules database). A self-learning neural network was created in the Matlab environment (see Figure 8), where four fuzzy models were created, one for each force $F_{x \min}$, $F_{x \max}$, $F_{y \min}$, and $F_{y \max}$ (Piegat, 1999).

Figures 9–12 show the interface of the Sugeno model and the sample calculations of $F_{x \min}$, $F_{x \max}$, $F_{y \min}$, and $F_{y \max}$ for the variables $DWT_1/DWT_0 = 2.71$, $H/T = 2$, and $s = 1B$, and for the speed in turn: $V = 2.66$ m/s, $V = 2.88$ m/s, $V = 3.21$ m/s, and $V = 3.42$ m/s.

Figure 9. Interface of the SUGENO model with $V = 3.42$ m/s ($DWT_1/DWT_0 = 2.71$, $H/T = 2$, and $s = 1B$)Figure 11. Interface of the SUGENO model with $V = 3.21$ m/s ($DWT_1/DWT_0 = 2.71$, $H/T = 2$, and $s = 1B$)Figure 10. Interface of the SUGENO model with $V = 2.66$ m/s ($DWT_1/DWT_0 = 2.71$, $H/T = 2$, and $s = 1B$)Figure 12. Interface of the SUGENO model with $V = 2.88$ m/s ($DWT_1/DWT_0 = 2.71$, $H/T = 2$, and $s = 1B$)

The user-friendly interface of the SUGENO model enables the easy modeling of the speed and side distance using sliders or typing the numerical values; the values of the maximum forces are thus instantly seen (Świercz, 2015). Based on expert knowledge, considering average mooring construction, we find the following:

- ships mooring devices and equipment (SWL);
- energy absorbing ability of port fenders and solid berths;
- mooring set up in average 2 lines + 1 spring line fore and aft.

It can be concluded that the maximum and minimum surge and sway forces should not exceed 50 T.

It should be noted that the DWT_1/DWT_0 and H/T variables appeared in the research only in the form of two values; therefore, the Sugeno model adopted a linear interpolation for these variables. The remaining variables, such as velocity and lateral distance, were measured in a sufficient amount for the Sugeno model to use three membership functions for them in the fuzzification process, which makes interpolation and extrapolation much more accurate (Trojanowska & Małopolski, 2005).

Results and conclusions

This article presents and discusses the results of the research carried out at the Ship Handling Research and Training Centre in Iława. The purpose of which was to simplify the method of predictive calculations in order to adjust the speed and distance when passing a moored ship, which ensures the safety of both vessels. The established database enables the answering of key questions for the passing of a moored ship, such as: Where does the interaction between the moored and passing ships begin? and What is the most dangerous relative position of ships?

A fuzzy model based on the Matlab computing environment was created, with the help of which it is possible to quickly determine the peak values of the hydrodynamic forces that arise during the interaction of a moored ship and a ship passing by. The study shows that fuzzy models enable the creation of stable, adaptive control systems without the need to conduct a large number of model tests. In addition, neural networks allow a correction and supplementation with expert knowledge of inaccurate fuzzy models.

The presented fuzzy model is based on the Sugeno model, a self-learning neural network that is characterized by high flexibility. Fuzzy models can be used for calculations for data outside the scope of the empirical research results. The proposed method can be implemented in the maritime transport safety management system in order to simulate the interaction of ships, and to determine the maximum permissible speed and distance to safely bypass moored ships in normal port traffic conditions.

Acknowledgment

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Use of the grey incidence analysis in the inland waterway transport system assessment

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JEL Classification: C44, L91, O18, R41

Abstract

Inland waterway transport (IWT) is currently in focus for EU countries due to a shift in policy towards a more sustainable and green economy. The aim of this article is to analyze the possibility of using a grey incidence analysis (GIA) to identify key factors related to the functioning of the IWT system. GIA is classified as a multi-criteria decision-making method and is one of the key applications of grey systems theory (GTS), i.e., systems with incomplete and uncertain information about structure and behavior. GIA identifies the most favorable (or quasi-preferred) system characteristics and the most favorable (or quasi-preferred) system factors. The identification of such characteristics and factors enables a reduction in the inconsistencies in decision making on the functioning of the system. The application of the GIA to the assessment of the IWT system is an original concept.

Introduction

Inland waterway transport (IWT) is an important sector of the economic activity of the European Union (EU) and its importance is increasing as countries move towards more sustainable and green economies. IWT is characterized by many features which, in the situation of well-developed waterways, make it possible to effectively compete with land transport, not just in terms of operating costs.

Low energy consumption in relation to the transport work performed, high load capacity of vessels and their versatility, high durability of infrastructure facilities and vessels as well as a relatively low nuisance for people and the environment are important, positive features of inland water transport compared to other modes of transport. It has long been the goal of EU countries to shift goods transport from roads

to greener means. Inland navigation is able to safely and reliably transport cargo (and passengers) in rivers, canals, lakes, and other waterways, including inside ports. Every year in the EU, transport performance of 150 billion ton-kilometers is performed on inland waterways. EUR 2.2 billion of added value in the IWT sector generates direct and indirect economic added value of EUR 13.2 billion. In addition, each of the five largest seaports in the EU is connected to inland waterways. The TEN-T corridor network (trans-European transport networks) includes 230 inland ports. About 75 of these ports are part of the core network and a further 40 of them are both inland and seaports. From the port of Rotterdam, about 1/3 of all goods are cleared by inland waterways (COM, 2006).

The European Green Deal has set the ambitious goal for EU economies to shift a significant

proportion of freight from road to rail and inland waterways. Although inland water transport currently accounts for only about 6.5% of freight transport, the direction of changes has already been indicated. The EU policy promotes solutions related to intermodality and the reduction of emissions and energy consumption of the transport system at the continental level (EC, 2011).

This requires increasing IWT capacity and improving their management from 2021 (COM, 2013). Therefore, transport and water management policies and measures must focus on adapting the technological and organizational aspects of inland navigation to the new guidelines and the new market demand structure. The subject of the article, which is to analyze the possibility of using grey incidence analysis (GIA) to identify key factors related to the functioning of the IWT system, fits perfectly into these activities.

Assessment of the inland waterway transport system functioning

On this subject in the literature, there are numerous studies on the functioning of inland water transport. The studies emphasize its properties and specificity and indicate the existing potential, measurable benefits, and possibilities of use (Kulczyk & Winter, 2003; Rolbiecki, Rydzikowski & Wojewódzka-Król, 2007; Hekkenberg & Thill, 2014; Wojewódzka-Król, 2015; Li, Notteboom & Wang, 2016; Woś & Han, 2017).

A lot of space has been devoted to the search for optimal solutions in the functioning of this type of transport (Fischetti & Toth, 1992; Charlier & Ridolfi, 1994; Zhang, Janic & Tavasszy, 2015). Organizational and legal issues are considered separately (Molnar, 2001; Semenov, 2006), as well as economic (Rozwój, 2016; Gus-Puszczewicz, 2018), technical, and technological issues (Tołkacz, 2010, 2011; Woś & Han, 2017) or ensuring safety during loading and unloading operations in harbor (Fraitag et al., 2022).

Some publications analyze issues that combine several different aspects (Semenov, 2005; Montwiłł, 2014; Wojewódzka-Król & Rolbiecki, 2014; Marin & Olaru, 2015; Wojewódzka-Król, 2015), or analyze one existing or prospective case (Petnga & Austin, 2016; Woś & Han, 2017). Decision-making problems relate to the shaping of transport networks and adapting individual infrastructure elements to the existing demand, distribution of traffic in the network, minimizing the time and costs of implementing

individual stages of transport processes, or the selection of solutions shaping a new dimension of transport infrastructure (Hrušovský et al., 2018; Tzannatos, Tselentis & Corres, 2016; Wang et al., 2019).

Operational research, linear programming, and game theory are used to analyze systemic transport problems (Nelson et al., 2017; Tanaka & Okada, 2019; Munuzuri et al., 2020). Some of the problems are formulated as a single-criteria optimization task and then the objective function is to minimize the time of the process, minimize costs, or maximize profits (Wiegman & Konings, 2015; Hofbauer & Putz, 2020). In this case, the constructed models are considered separately, which, however, does not lead to general formulations (Jacyna, 2001, 2009; Smoliński, 2014).

Transport problems are increasingly more often solved when using a multi-criteria approach, in which the problem of minimizing the target function is described, and where the partial criteria are, for example, transport cost, safety, service time, or the amount of cargo transported (Fischetti & Toth, 1992; Geneletti, 2005; Jacyna, 2009; Al Enezy et al., 2017; Hossain et al., 2020).

The assessment of the systems is made not only from the point-of-view of efficiency, but also safety, so that it is possible to identify more advantageous solutions that meet, above all, the expectations of potential users (Žak, Jacyna-Golda & Wasiak, 2014; Melo et al., 2017; Załoga, 2017; Dvorak et al., 2020). The use of a multi-criteria approach requires the use of multi-criteria decision support tools. These tools have been increasingly represented in recent years (Jacyna, 2001, 2009; Geneletti, 2005; Fazi, Fransoo & Van Woensel, 2015).

Characteristics of the Grey Incidence Analysis

Grey incidence analysis (GIA) is one of the most important decision-making methods in grey systems theory (GTS). Grey systems are systems with incomplete and uncertain information about structure and behavior (Deng, 1989). GTS does not require many assumptions about the size and distribution of the sample that is accepted for research – the minimum number of data must not be less than four. Therefore, it has an advantage over statistical methods, or fuzzy or coarse sets (Liu, Forrest & Yang, 2012; Rajesh & Ravi, 2015).

Using the theory of grey systems, it is possible to forecast the future behavior of the system, assess the interdependence of observation vectors, evaluate the

effectiveness of the system's reaction to possible situations, and make optimal decisions as well as group and study clusters. The basic assumption of the GIA is that the closeness of a relationship can be judged on the level of similarity in the geometric patterns of the sequence curves. The more similar the curves are, the higher the degree of similarity between the sequences exists, and vice versa (Liu & Lin, 2010).

The measure of the similarity of vectors is the so-called relative degree of incidence (similarity) between the observation vectors X_i and Y_j , where Y represents the system responses and X the system influencing factor. The relative degree of incidence (similarity) between the observation vectors X_i and Y_j has properties that are very important for system evaluation (Liu & Lin, 2010):

- (a) $0 < R_{ij} \leq 1$;
- (b) R_{ij} is related only to the geometrical shape of the vectors X_i and Y_j , but not to their spatial arrangement;
- (c) every two vectors are always at least minimally related, so R_{ij} is not zero;
- (d) the more the observation vectors are related (similar), the higher the value of R_{ij} ;
- (e) if the observation vectors are parallel or fluctuate around one another, the value of R_{ij} is equal to or close to 1;
- (f) if one of the vectors changes, R_{ij} also changes;
- (g) if the length of the vectors changes, so does R_{ij} ;
- (h) identity relationship ($R_{ii} = R_{jj} = 1$) and the symmetry relation ($R_{ij} = R_{ji}$) are used.

The relative degree of incidence enables a good assessment of the similarity of the behavior of the vector pair, as well as the degree of their relationship. This enables the most favorable system characteristics and factors to be identified according to the guidelines below (Liu & Lin, 2010):

- If there are k and $i \in \{1, 2, \dots, s\}$ satisfying $R_{kj} \geq R_{ij}$, for $j = 1, 2, \dots, m$, then the system characteristic Y_k is more favorable than Y_i , denoted as $Y_k > Y_i$. If for any $i = 1, 2, \dots, s$, there is always $Y_k > Y_i$, then Y_k is the most favorable feature of the system. This means that Y_k is the most advantageous sequence to describe the system characteristics.
- If there are l and $j \in \{1, 2, \dots, m\}$ satisfying $R_{il} \geq R_{ij}$, for $i = 1, 2, \dots, s$, then the corresponding factor X_l is more favorable than X_j , written as $X_l > X_j$. If for any $j = 1, 2, \dots, m$, there is always $X_l > X_j$, then X_l is the most favorable system factor. This means that X_l is the most favorable system factor that will influence the future development of this system.

There may not be the most favorable system characteristic and factor in a system. However, there are always quasi-preferred system characteristics and factors that can be identified according to the following guidelines (Liu & Lin, 2010):

- If there are k and $i = 1, 2, \dots, s$ satisfying $\sum_{j=1}^m R_{kj} \geq \sum_{j=1}^m R_{ij}$ then the characteristics of the Y_k system are more quasi-favorable than Y_i , which means $Y_k \geq Y_i$. If for any $i = 1, 2, \dots, s$, there is always $Y_k \geq Y_i$, then Y_k is the quasi-preferred characteristic of the system. This means that Y_k is more appropriate to describe the system characteristics compared to other characteristics.
- If there are l and $j \in \{1, 2, \dots, m\}$, satisfying $\sum_{i=1}^s R_{il} \geq \sum_{i=1}^s R_{ij}$ the corresponding factor X_l is more favorable than X_j , which is $X_l \geq X_j$. If for any $j = 1, 2, \dots, m$ there is always $X_l \geq X_j$, X_l is the quasi-preferred system factor. This means that X_l is a more appropriate system factor to influence the future development of that system as compared to the other factors.

Therefore, the method is widely used in the analysis of various systems (Cui, Zhou & Liu, 2009; Goyal & Grover, 2012; Karimi & Forrest, 2014; Tan et al., 2014; Guo & Zhang, 2015; Wang, Liu & Bi, 2015; Liu et al., 2016; Xie, Hu & Yin, 2016; Zhu et al., 2016; Tabor, 2018, 2021).

Methodology

Based on the literature, three main indicators of the effects of the inland water transport system have been established, which have been adopted as the system characteristics: Y_1 – production value (million euro), Y_2 – value added at factor cost (million euro), and Y_3 – turnover or gross premiums written (million euro). At the same time, the following indicators were adopted as systemic factors: X_1 – navigable inland waterways – all waterways type (kilometer), X_2 – inland freight water transport enterprises (number), X_3 – persons employed (number), X_4 – self-propelled barge (number), X_5 – self-propelled barge (thousand tones), X_6 – dumb and pushed vessel (number), X_7 – dumb and pushed vessel (thousand tones), X_8 – power of self-propelled vessels by load capacity (megawatt), X_9 – total transported goods (thousand tones), and X_{10} – investment (million euro). The EUROSTAT database was used as the data source; data related to 2019.

To identify the most important characteristics of the inland water transport system and system factors, the GIA procedure algorithm was used, including the following activities (Liu et al., 2016):

1) Building a sequence of system characteristics and the sequence of system factors. If $Y_1, Y_2, \dots, Y_s$ is a series of system characteristics, and $X_1, X_2, \dots, X_m$ is a series of system factors, n is the number of observation values for $y_i(k)$ and $x_j(k)$ where $(k = 1, 2, \dots, n; j = 1, 2, \dots, m)$, then the sequences of the system characteristic Y_i and the sequences of the system factor X_j can be expressed by the following formulas:

$$Y_i = (y_i(1), y_i(2), \dots, y_i(k), \dots, y_i(n)), i = 1, 2, \dots, s$$

$$X_j = (x_j(1), x_j(2), \dots, x_j(k), \dots, x_j(n)), j = 1, 2, \dots, m$$

2) Calculation of the initial image of Y_i and X_j . The initial images of Y_i and X_j are calculated using equations that transform the values of the observations into dimensionless values, so that:

$$\begin{aligned} Y'_i &= \frac{Y_i}{y_i(1)} = (y'_i(1), y'_i(2), \dots, y'_i(k), \dots, y'_i(n)) \\ i &= 1, 2, \dots, s \\ X'_j &= \frac{X_j}{x_j(1)} = (x'_j(1), x'_j(2), \dots, x'_j(k), \dots, x'_j(n)) \\ j &= 1, 2, \dots, m \end{aligned} \quad (1)$$

where:

$$\begin{aligned} y'_i(k) &= \frac{y_i(k)}{y_i(1)}, \quad k = 1, 2, \dots, n \\ x'_j(k) &= \frac{x_j(k)}{x_j(1)}, \quad k = 1, 2, \dots, n \end{aligned}$$

3) Compute the images of the zero starting points of Y'_i and X'_j . Images of the zero starting points of Y'_i and X'_j are presented by the following equations:

$$\begin{aligned} Y_i^{r0} &= (y_i^{r0}(1), y_i^{r0}(2), \dots, y_i^{r0}(k), \dots, y_i^{r0}(n)) \\ i &= 1, 2, \dots, s \\ X_j^{r0} &= (x_j^{r0}(1), x_j^{r0}(2), \dots, x_j^{r0}(k), \dots, x_j^{r0}(n)) \\ j &= 1, 2, \dots, m \end{aligned} \quad (2)$$

where:

$$\begin{aligned} y_i^{r0}(k) &= y'_i(k) - y'_i(1), \quad k = 1, 2, \dots, n \\ x_j^{r0}(k) &= x'_j(k) - x'_j(1), \quad k = 1, 2, \dots, n \end{aligned}$$

4) Calculation of $[s_i]$ and $[s_j]$ using the following equations:

$$\begin{aligned} |s_i| &= \left| \sum_{k=2}^{n-1} y_i^{r0}(k) + \frac{1}{2} y_i^{r0}(n) \right|, \quad i = 1, 2, \dots, s \\ |s_j| &= \left| \sum_{k=2}^{n-1} x_j^{r0}(k) + \frac{1}{2} x_j^{r0}(n) \right|, \quad j = 1, 2, \dots, m \\ |s'_j - s'_i| &= \left| \sum_{k=2}^{n-1} (x_j^{r0}(k) - y_i^{r0}(k)) + \frac{1}{2} (x_j^{r0}(n) - y_i^{r0}(n)) \right| \\ i &= 1, 2, \dots, s; \quad j = 1, 2, \dots, m; \quad k = 1, 2, \dots, n \end{aligned} \quad (3)$$

5) Compute the relative degree of grey similarity r_{ij} and obtain the relative grey similar matrix $\mathbf{R}$. The relative degree of grey similarity r_{ij} is expressed by the following expression:

$$r_{ij} = \frac{1 + |s'_i| + |s'_j|}{1 + |s'_i| + |s'_j| + |s'_j - s'_i|} \quad i = 1, 2, \dots, s; \quad j = 1, 2, \dots, m \quad (4)$$

So, we can obtain the relative grey similarity matrix $\mathbf{R}$. The entries in the i -th row ($i = 1, 2, \dots, s$) and in the j -th column ($j = 1, 2, \dots, m$) are the relative degrees of the grey sequence similarity of the Y_i characterization and the factor X_j sequence for the system:

$$\mathbf{R} = [r_{ij}]_{s \times m} = \begin{bmatrix} r_{11} & r_{12} & \dots & r_{1m} \\ r_{21} & r_{22} & \dots & r_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ r_{s1} & r_{s2} & \dots & r_{sm} \end{bmatrix}_{s \times m}$$

6) Analyze the relative grey similarity matrix $\mathbf{R}$ and identify the most favorable (or quasi-preferred) system features and system factors.

Findings

The structure of the sequence of IWT system characteristics and factors was based on EUROSTAT indicators from only 9 countries: Bulgaria, Croatia, Czechia, Finland, France, Germany, Poland, Romania, and Slovakia (Table 1). In the case of other countries, the databases were incomplete (the data has not been made available).

Using the data from Table 1, the initial images of the sequence of Y characteristics and the sequence of X factors were calculated according to the formula (1). Table 2 presents the results of these calculations.

Using formula (2), and values taken from Table 2, the zero images of the initial points of the sequence of Y characteristics and the sequence of X factors were calculated. The obtained results are summarized in Table 3.

Table 1. Observation values of IWT characteristic and IWT factors (EUROSTAT, 2022)

	IWT Characteristics Y			IWT Factors X									
	y_1	y_2	y_3	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}
BG	29.4	7.4	28.6	470	25	534	34	52.5	106	179.6	28.8	18,449	161.8
HR	2.5	-0.1	2.5	1016.9	5	45	15	16	98	75	10	6491	31.1
CZ	28.8	5.0	29.4	720	25	287	33	33	95	50	15	779	81.1
FI	6.3	2.0	8.0	8125	10	51	189	16	55	8	40	527	133.6
FR	400	161.4	397.3	4827	660	1941	700	639	342	453	307	64,207	5229.4
DE	1036.7	530.2	1715.4	7675	549	4981	1171	1805	805	740	892	205,066	11,272.2
PL	44.4	9.1	45.5	3722.2	261	593	80	62	402	183	30	2870	235.9
RO	121.4	38.2	114.9	2635	72	1574	123	160	1021	1448	83	33,261	1345.5
SK	37.3	9.1	74.7	172	19	301	9	10.6	99	159.6	4.2	6430	3382.7

BG – Bulgaria, HR – Croatia, CZ – Czechia, FI – Finland, FR – France, DE – Germany, PL – Poland, RO – Romania, SK – Slovakia. Y_1 – production value (million euro), Y_2 – value added at factor cost (million euro), Y_3 – turnover or gross premiums written (million euro), X_1 – navigable inland waterways – all waterways type (kilometer), X_2 – inland freight water transport enterprises (number), X_3 – persons employed (number), X_4 – self-propelled barge (number), X_5 – self-propelled barge (thousand tones), X_6 – dumb and pushed vessel (number), X_7 – dumb and pushed vessel (thousand tones), X_8 – power of self-propelled vessels by load capacity (megawatt), X_9 – total transported goods (thousand tones), and X_{10} – investment (million euro).

Table 2. Initial images of Y_i and X_j

	$y_1(k)$	$y_2(k)$	$y_3(k)$	$x_1(k)$	$x_2(k)$	$x_3(k)$	$x_4(k)$	$x_5(k)$	$x_6(k)$	$x_7(k)$	$x_8(k)$	$x_9(k)$	$x_{10}(k)$
BG	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
HR	0.09	-0.01	0.09	2.16	0.20	0.08	0.44	0.30	0.92	0.42	0.35	0.35	0.19
CZ	0.98	0.68	1.03	1.53	1.00	0.54	0.97	0.63	0.90	0.28	0.52	0.04	0.50
FI	0.21	0.27	0.28	17.29	0.40	0.10	5.56	0.30	0.52	0.04	1.39	0.03	0.83
FR	13.61	21.81	13.89	10.27	26.40	3.63	20.59	12.17	3.23	2.52	10.66	3.48	32.32
DE	35.26	71.65	59.98	16.33	21.96	9.33	34.44	34.38	7.59	4.12	30.97	11.12	69.67
PL	1.51	1.23	1.59	7.92	10.44	1.11	2.35	1.18	3.79	1.02	1.04	0.16	1.46
RO	4.13	5.16	4.02	5.61	2.88	2.95	3.62	3.05	9.63	8.06	2.88	1.80	8.32
SK	1.27	1.23	2.61	0.37	0.76	0.56	0.26	0.20	0.93	0.89	0.15	0.35	20.91

Table 3. Images of zero starting points of initial images Y_i and X_j

	$y_1^0(k)$	$y_2^0(k)$	$y_3^0(k)$	$x_1^0(k)$	$x_2^0(k)$	$x_3^0(k)$	$x_4^0(k)$	$x_5^0(k)$	$x_6^0(k)$	$x_7^0(k)$	$x_8^0(k)$	$x_9^0(k)$	$x_{10}^0(k)$
BG	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
HR	-0.91	-1.01	-0.91	1.16	-0.80	-0.92	-0.56	-0.70	-0.08	-0.58	-0.65	-0.65	-0.81
CZ	-0.02	-0.32	0.03	0.53	0.00	-0.46	-0.03	-0.37	-0.10	-0.72	-0.48	-0.96	-0.50
FI	-0.79	-0.73	-0.72	16.29	-0.60	-0.90	4.56	-0.70	-0.48	-0.96	0.39	-0.97	-0.17
FR	12.61	20.81	12.89	9.27	25.40	2.63	19.59	11.17	2.23	1.52	9.66	2.48	31.32
DE	34.26	70.65	58.98	15.33	20.96	8.33	33.44	33.38	6.59	3.12	29.97	10.12	68.67
PL	0.51	0.23	0.59	6.92	9.44	0.11	1.35	0.18	2.79	0.02	0.04	-0.84	0.46
RO	3.13	4.16	3.02	4.61	1.88	1.95	2.62	2.05	8.63	7.06	1.88	0.80	7.32
SK	0.27	0.23	1.61	-0.63	-0.24	-0.44	-0.74	-0.80	-0.07	-0.11	-0.85	-0.65	19.91

Then, using formulas (3), the S components were calculated (Table 4). The S components are necessary to compute the relative grey degrees of similarity with R , these are: $S_{i=1} = 48.92$, $S_{i=2} = 93.90$, $S_{i=3} = 74.68$.

The next step was to calculate the relative degrees of grey similarity and present them in the form of the R matrix. The formula (4) was used for the calculations, to find that (5).

$$R = [r_{ij}]_{3 \times 10} = \begin{bmatrix} 0.9552 & 0.9362 & 0.6115 & 0.9044 & 0.9564 & 0.7028 & 0.6002 & 0.9136 & 0.6027 & 0.7117 \\ 0.7875 & 0.8001 & 0.5584 & 0.8236 & 0.7390 & 0.6062 & 0.5525 & 0.7165 & 0.5538 & 0.9044 \\ 0.8610 & 0.8768 & 0.5733 & 0.9063 & 0.8001 & 0.6333 & 0.5659 & 0.7719 & 0.5675 & 0.8220 \end{bmatrix} \quad (5)$$

Table 4. Values of the S components for the calculation of R

	$j = 1$	$j = 2$	$j = 3$	$j = 4$	$j = 5$	$j = 6$	$j = 7$	$j = 8$	$j = 9$	$j = 10$
$ S'_j $	53.79	56.16	10.52	60.60	44.62	19.55	9.41	40.39	9.65	116.23
$ S'_j - S'_{i=1} $	4.87	7.24	38.41	11.68	4.31	29.37	39.52	8.54	39.27	67.31
$ S'_j - S'_{i=2} $	40.11	37.75	83.39	33.30	49.29	74.35	84.50	53.52	84.25	22.33
$ S'_j - S'_{i=3} $	20.89	18.53	64.17	14.08	30.07	55.13	65.28	34.30	65.03	41.55

Finally, a matrix analysis was performed to identify the most favorable (or quasi-preferred) characteristics and the most favorable (or quasi-preferred) factors:

$$\sum_{j=1}^{10} r_{1j} = 7.8947 \geq \sum_{j=1}^{10} r_{3j} = 7.3782 \geq \sum_{j=1}^{10} r_{2j} = 7.0419$$

$$Y_1 \geq Y_3 \geq Y_2$$

The analysis of the results shows that the most favorable characteristic for the inland water transport system is *production value in million euro*. At the same time, the most favorable system factors are: *number of self-propelled barges* and *number of inland freight water transport enterprises* as well as *navigable inland waterways – all waterways type (in kilometer)*. It is determined that:

$$\sum_{i=1}^3 r_{i4} = 2.6344 \geq \sum_{i=1}^3 r_{i2} = 2.6130 \geq \sum_{i=1}^3 r_{i1} = 2.6038 \geq$$

$$\sum_{i=1}^3 r_{i5} = 2.4955 \geq \sum_{i=1}^3 r_{i10} = 2.4381 \geq \sum_{i=1}^3 r_{i8} = 2.4020 \geq$$

$$\sum_{i=1}^3 r_{i6} = 1.9424 \geq \sum_{i=1}^3 r_{i3} = 1.7431 \geq \sum_{i=1}^3 r_{i9} = 1.7239 \geq$$

$$\geq \sum_{i=1}^3 r_{i7} = 1.7186$$

$$\sum_{i=1}^3 r_{ij}, (j=1,2,3)$$

$$X_4 \geq X_2 \geq X_1 \geq X_5 \geq X_{10} \geq X_8 \geq X_6 \geq X_3 \geq X_9 \geq X_7$$

Conclusion and discussion

Shipping companies has to be able to safely and reliably transport cargo, reduce traffic congestion, and provide lower energy consumption and improved environmental performance. According to EUROSTAT data in 2019, Finland (8125 in kilometers), Germany (7675), and the Netherlands (6297) had the longest waterways. On the other hand, most goods were transported by the Netherlands (357,069 in thousand tons), Germany (205,066), and Belgium (155,695).

At the same time, the length of the roads and the number of transported goods does not always translate directly into the production value. Moreover, in times of sustainable development and green economy, the value of production or other purely financial indicators should not be the only important measures – characteristics of the functioning of the system. The performance of a system is usually influenced by many factors, of a very different nature. Therefore, in order to reliably assess the functioning of the system in the modern economy, it is necessary to identify the characteristics and system factors describing the system from various points-of-view (technical, organizational, human, and environmental) and with the use of various measures (quantitative and qualitative).

This paper represents the original application of the GIA to identify key characteristics and the most favorable system factors in the assessment of an IWT system. It is true that the analysis used little differentiated characteristics and systemic factors, but it resulted from the access to such data. During the pandemic, conducting questionnaire surveys was unfortunately difficult. This is the main limitation of the research.

On the other hand, the choice of a method in the area of GTS is perfectly justified, because GIS enables the use of not only quantitative but also qualitative data, which may contribute to further research on this topic. The proposed approach has the following advantages: (a) it is relatively easy to apply, (b) it is beneficial in the situation of imprecise and incomplete information, and (c) it can be applied even in the case of a small sample. Using the proposed approach, the most favorable characteristic of the inland water transport system is the *production value in million euro* and the most favorable system factors are *number of self-propelled barges* and *number of inland freight water transport enterprises* as well as *navigable inland waterways – all waterways type in kilometer*.

The application of the GIA in the area of IWT is an original concept. The proposed approach could be an important tool for the assessment and improvement of the inland water transport system.

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Ship nonlinear roll motion identification using artificial neural network

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Abstract

The solution of the nonlinear equation for a ship's rotational motion around its longitudinal axis, even with simplifying assumptions, is complicated. This oscillatory motion, which is known as the roll motion, is generated when the ship sails in the waves, and the irregular behavior of the waves causes time-varying dynamics. Calculating the ship's roll response is possible by determining roll equation coefficients. In the current study, the coefficients were determined from the dynamic response of the ship using a training feed-forward neural network. The training was carried out in two modes: as a free swing in calm water and forced oscillation in irregular waves. The DTMB 5415 vessel was selected as the case study ship. The results of the simulation by the neural network were validated by numerical analysis and model test results.

Symbols and abbreviations

Symbol	Description, unit		
A	Total inertia coefficient, $\text{kg} \cdot \text{m}^2$	K''_{xx}	Total mass radius of gyration around x -axis, m
B	Damping coefficient, $\text{kg} \cdot \text{m}^2/\text{s}$ or ship breadth, m	LCB	Ship longitudinal center of buoyancy, m
C	Restoring coefficient, $\text{N} \cdot \text{m}$	VCG	Ship vertical center of gravity, m
dr	Roll decrement, deg	I_{xx}	Inertia coefficient, $\text{kg} \cdot \text{m}^2$
Δ	Ship displacement, kg	t	Time, s
F	Environmental force, $\text{N} \cdot \text{m}$	t_S	Swing period, s
GZ	Ship righting arm, m	AP	Ship aft perpendicular
K_{xx}	Mass radius of gyration around x -axis, m	d_P	Network desired output
K'_{xx}	Added mass radius of gyration around x -axis, m	F_n	Froude number
		f	Neural network transfer function
		FP	Forward perpendicular
		μ	Network training error
		NN	Neural Network

w, u, s, v	Weight coefficient in NN layers
x	NN inputs
y	NN layers outputs
Y	NN transfer function outputs
z_P	Network normal output
WL	Water line
μ, η, δ	Training error back propagation coefficient
α	Training momentum coefficient

Introduction

Rotational motion about the longitudinal axis, referred to as roll, is usually created when a ship moves through the waves. This motion is important in the seakeeping performance of the vessels. Many dynamic effects such as seasickness, equipment performance, and personnel performance, depend on this motion. The simulation of the roll motion of the ship is necessary in the design phase for determining the seakeeping performance of the vessel. A simple and practical method for the calculation of seakeeping is the strip theory or potential method, which is elaborated in the primary references of seakeeping. The investigation of relevant articles and references shows that this method provides acceptable results for the ship's vertical plane motions, including the pitch and heave. However, for the roll motion of the ship, especially in nonlinear conditions, this method gives significant errors due to its failure to consider damping effects due to fluid viscosity. Calculating the roll response is possible through the definition of the nonlinear hydrodynamic coefficients of the roll motion equation.

There are numerous articles and publications related to roll motion and ship motion control. The reference books, "Dynamics of marine vehicles" written by R. Bhattacharyya, 1978, and "Principles of Naval Architecture" by Edward V. Lewis, 1989, are the primary references for such articles. The dynamics of roll motion in this paper have been retrieved from these references.

Mahfouz (Mahfouz, 2004) dealt with the determination of the nonlinear equation of roll motion by measuring a ship's response in the sea. In this study, the linear and nonlinear coefficients and parameters were calculated by using an NN for the free oscillation and the roll motion oscillation under a regular exciting moment. The ship's roll motion response was considered as the input and the exciting roll moment as the output of the network. Xing and McCue (Xing & McCue, 2010), in a similar manner to Mahfouz (Mahfouz, 2004), used a feed-forward NN. In this network, the roll motion responses are

input values and the roll motion equation coefficients and the exciting moment are the output values from which, after being placed in the roll motion differential equation, the roll motion response is extracted again and compared to the network's input. This error is used for the adjustment of the network's weights. The problem of this method is in the training of the NN. Generally, in NN-supervised training, the difference between the desired output and network output comprises the error function, which is used for backpropagation and weight modification. In this study, the network outputs are coefficients and exciting forces, and there are no desired values for these parameters, so the network outputs used for solving the motion equation, the response extracted, and the difference between the extracted response and the input response form the error function. Due to the complexity of the relationship between the response error and network output, the network has uncertainty. This uncertainty in the irregular motion leads to erroneous results, and its application in controlling the motion leads to the intensification of motion due to inadaptability (Perez & Blanke, 2002).

In many of the articles, such as those of Alarçin (Alarçin, 2007), Ghassemi et al. (Ghassemi et al., 2010), Oskin et al. (Oskin, Dyda, & Markin, 2013), and Awad et al. (Awad, Elgohary, & Mohamed, 2018), the NN was paralleled by linear control systems, such as PID or LQR. The network was trained to imitate controller behavior, and its performance was compared to control systems. In these studies, artificial NNs were more stable and performed better.

Hou et al. (Hou, Zou & Liu, 2018), in a similar study to that of Mahfouz (Mahfouz, 2004), determined the nonlinear damping and restoring moments by a combination of the random decrement technique (RDT) and support vector regression. In the study by Hou et al., damping and restoring moments were considered as a combination of linear and nonlinear parts. Auto and cross-correlation functions and training samples were used to find the linear part, while by using the training sample and random decrement signature, nonlinear parts were identified, and by the numerical solution the roll motion was simulated. In the study by Hou et al., a semi-regular exciting force was assumed.

Method of work

Dynamic identification of floating structures is an essential field in marine studies. The design of a ship's dynamic control systems is viable when the dynamics of the ship as a system are identified. The

determination of the nonlinear hydrodynamic coefficients of roll motion is not possible by simplifying assumptions and is very complicated in irregular waves. Recording the dynamic response using laboratory tests or during sailing is possible. However, the roll exciting moment cannot be recorded, which is one of the problems in the definition of the coefficients. Dynamic system identification in sea-keeping is complicated and requires time and costly experiments.

In the current study, a method for simulation of the nonlinear roll of the ship is proposed, employing a feed-forward artificial NN. The input layer of this network included the motion response, and the output layer of this network was the roll motion equation coefficients. This network had three hidden layers with 27 neurons with bipolar sigmoid functions and linear output. The desired values for the output included the coefficient of the rotational moment of inertia, damping, and the restoring coefficient.

The training of the NN was carried out in two phases. In the first phase, the network was trained using free rolling in calm water and various speeds, and the simulation results were compared to the test results. In the second phase, this network was trained by CFD simulation in irregular waves. Finally, the simulation from the NN was compared with the CFD simulation. The investigations of the current study indicated that the two-phase training was very effective, and that training convergence in the second phase was viable by using the first stage training as the initial conditions.

Table 1. The specifications of the prototype ship

Particular	Prototype
Length overall, m	153.230
Length between perpendiculars, m	142.000
Breadth max molded, m	20.546
Breadth molded on WL, m	19.060
Draught molded on FP, m	6.150
Draught molded on AP, m	6.150
Displacement, m ³	8431.800
Wetted surface area, m ²	2972.600
LCB Position aft of FP, m	71.970
Transverse metacentric height, m	1.950
VCG, m	7.510
Natural period of roll, m	11.500
Block coefficient	0.507
Mass radius of gyration around x-axis	7.620
Mass radius of gyration around y-axis	35.500
Mass radius of gyration around z-axis	35.500
Max Speed, m/s	15.432

The DTMB 5415 ship was used as the case study model. This model is a well-known ship research model that is used by researchers, and the results of the studies are shared on the model's reference website. The dimensions of the selected model are the laboratory model IHRR with a scale of 46.588. It has a length of 3 meters and a weight of 83.4 kg. Table 1 presents the case study model specifications (Irvine, Longo & Stern 2004).

Governing equations

The roll motion, in common with many dynamic phenomena, follows Newton's Second Law. The nonlinear change of the equation coefficients leads to the impossibility of a direct solution. However, it can be solved using numerical methods. The equation for this motion can be written as follows:

$$A\ddot{x} + B\dot{x} + Cx = F \quad (1)$$

In this equation, (A) is the rotational inertia coefficient, (B) is the damping coefficient, and (C) is the restoring moment coefficient. The coefficients are dependent on the ship's dynamics and environmental conditions. Based on this equation, the exciting moment from sea waves applied to the ship causes the roll acceleration of the object (first term), a part of it being lost as damping (second term), and a part of it is used for increasing the object's potential in the form of restoring moment (third term). As a simple description, the ship roll motion is similar to the vibrational motion of its mass acting as a simple-mode spring moving in a free or forced manner. An oscillating motion of the ship is usually created due to its movement through the waves. Regarding the irregularity of the waves, the exciting moment would also be irregular. On the other hand, the shape of the ship's hull, equilibrium, and wave heading lead to the variability of the restoring coefficient. The inertia coefficient and damping coefficient of the ship are also a function of the rolling angle and the forward speed.

Artificial neural network

An artificial NN is a simplified model of the brain's NN. Figure 1 shows the simplified mathematical model of an artificial neural cell. In this model, an input value (x), after being strengthened (or weakened) by the parameter (w), with the size of (xw), enters the neuron in the form of an electrical signal. The summation of input signals obtained as $[(\sum xw) + v]$ undergoes another operation or process,

which is technically called a “transfer function”. The input of this box is $[(\sum xw) + v]$, and the output is designated as y . Parameter w is called the “weight parameter” (Jain, Mao, & Mohiuddin, 1996).

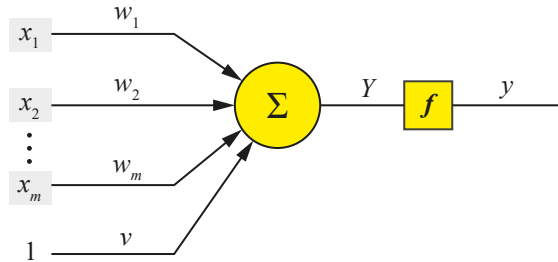


Figure 1. Neuron's mathematical model

An NN typically consists of many cells. The behavior of the network, in addition to being dependent on the transfer functions, depends on the weight parameters. In such a network, the weight parameters must be initialized and adjusted, so that the network has an appropriate mapping between input and output values. This process, in NN science, is called the training process. In practice, the transfer functions are usually a type of sinusoidal function, hyperbolic tangent, sigmoid, or the like. This transfer function transforms the input signals' combination to an output signal whose value can be between $-1 \sim 1$ or $0 \sim 1$ (Jain, Mao & Mohiuddin 1996). Two or more neurons can combine in a layer of the network. Also, a network may have one or several layers. Figure 2 shows a multilayer network.

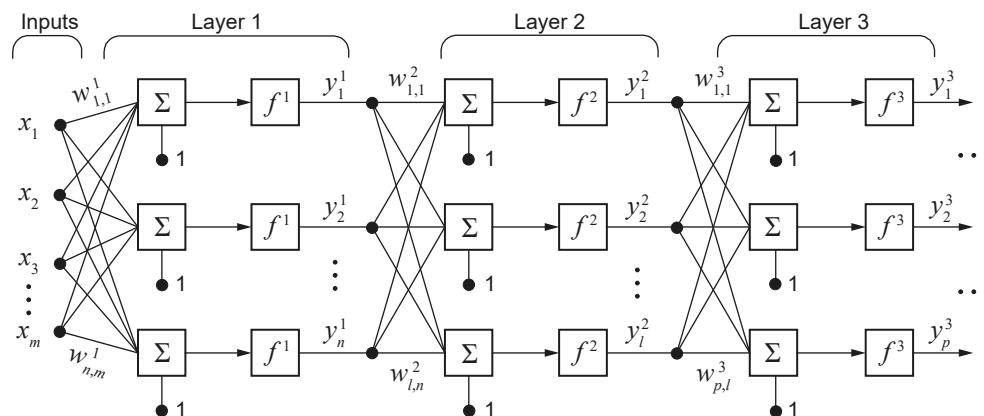


Figure 2. Multilayer network

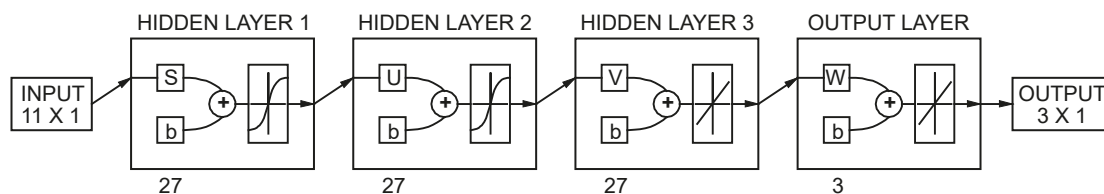


Figure 3. NN for prediction of nonlinear roll equation coefficients

Network training is based on the network error, which is the difference between the network output and the desired output. One of the well-known and practical methods of network training is backpropagation or, in other words, adjustment of the weights of the layers based on the output error function. In the next section, this method is presented for the roll motion artificial NN.

Nonlinear roll artificial neural network structure

Figure 3 shows the structure of the NN used in the current study. The input matrix was the ship's motion response, including the Froude number, displacement, velocity, and acceleration of the roll, pitch, and heave motions. Considering the values of the pitch and heave motions means that the effects of other degrees of freedom on the roll motion coefficients are considered, and this is a prominent feature of this study.

The input layer of this network was the following matrix.

$$\text{Input} = [\text{Fn} \ \Delta \ x_1 \ \dot{x}_1 \ \ddot{x}_1 \ x_2 \ \dot{x}_2 \ \ddot{x}_2 \ x_3 \ \dot{x}_3 \ \ddot{x}_3]^T \quad (2)$$

Indices 1, 2, and 3 were indicative of the degrees of freedom of the roll, pitch, and heave, respectively in equation (2). The output matrix had three arrays, shown as the following matrix (Eq. (3)).

$$\text{Output} = [A \ B \ C]^T \quad (3)$$

The desired output matrix is also presented as equation (4). Index d indicates the desired value of these parameters.

$$\text{Output} = [A_d \ B_d \ C_d]^T \quad (4)$$

The output matrix of this network had three values: the moment of inertia, damping, and restoring coefficients of the roll motion equation. The provision of correct or desired data is important in NN training. In the following section, the computation of the desired values for the network is presented. The provision of the training data is made simpler and less costly by using a model-scale ship. Therefore, the use of dimensionless or scaled coefficients is preferable for network training. In this case, the trained network would also be usable for a real-size ship.

Moment of inertia coefficient

Coefficient A is the moment of inertia plus added moment of inertia, which is expressed as follows (Bhattacharyya, 1978):

$$A = I_{xx} + \delta I_{xx} \quad (5)$$

$$A = \Delta k_{xx}^2 + \Delta k_{xx}'^2 = \Delta(k_{xx}^2 + k_{xx}'^2) = \Delta k_{xx}''^2 \quad (6)$$

For a frigate ship, the experimental equation (7) is suggested (Bhattacharyya, 1978). The added moment of inertia depends on the encounter between wave frequency and motion frequency. The obtained value from the equation below is assumed to be the fixed initial value for all the inputs, and it is adjusted in the section *Nonlinear damping coefficient*, with some changes.

$$\begin{aligned} & \left(\frac{K_{xx}''}{B} \right)^2 = \\ & = 0.172 \left[C_B C_u + 1.10 C_e (1 - C_B) \left(\frac{H_n}{d} - 2.2 \right) + \frac{H_n^2}{B_u^2} \right] \end{aligned} \quad (7)$$

$$H_n = D + \frac{A_n}{L_{pp}} \quad (8)$$

In this equation, the unit of the parameters with dimensions is the appropriate SI unit. The parameters are as follows:

- B – total breadth of the ship,
- C_B – block coefficient,
- C_u – total ship's deck area coefficient,

- C_e – ship's deck area exposed to air coefficient,
- d – ship's draft,
- B_u – waterline breadth,
- D – depth of the main deck,
- A_n – the side area of the superstructure above the main deck.

Restoring moment coefficient

When the ship is inclined in the direction of the roll motion, a coupled moment between gravity and buoyancy is created, which tries to return the ship to the initial position. This moment is known as the restoring moment (Figure 4).

$$C_d x = \Delta GZ(x) \quad (9)$$

$$\Delta GZ(x) = c_1 x + c_2 x^2 + c_3 x^3 + c_4 x^4 + c_5 x^5 = C_d x \quad (10)$$

$$\Rightarrow C_d = c_1 + c_2 x + c_3 x^2 + c_4 x^3 + c_5 x^4 \quad (11)$$

The following figure shows the values of ΔGZ .

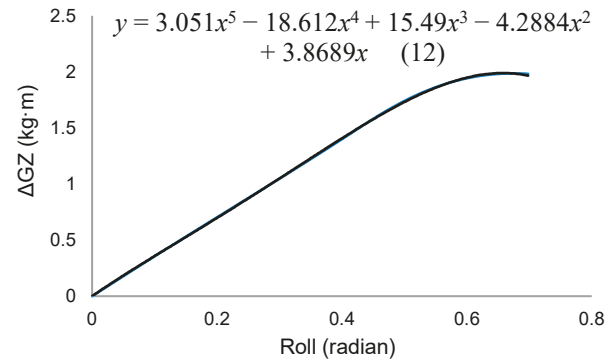


Figure 4. ΔGZ chart

Figure 4 shows the GZ curve of the ship under operational loading. This curve is variable for different values of trim and draft. Therefore, this curve can be drawn for a range of these variables, and the desired restoring coefficient (C_d) can be interpolated and calculated based on the network input. For the precision of Figure 4, a 40-degree range (0.7 radians) was considered.

Similarly to the inertia coefficient, the constant coefficients of this equation can also be scaled to the λ coefficient with the desired ratio. As was mentioned before, the dimensionless or scalable coefficients made the use of a model-scale ship instead of a real-size ship possible and reduced the computational volume. On the other hand, the trained network would be usable for the main ship.

Nonlinear damping coefficient

The desired value, for each input of the network for the damping coefficient, can be calculated by equation (13).

$$B_d = \frac{F - C_d \dot{x} - A\ddot{x}}{\dot{x}} \quad (13)$$

The important point in the preparation of the training data is that a damping coefficient is a positive value, and its value should not be considerably larger than the mean value. If this coefficient is negative, or its absolute value is large, it means that the considered values for the restoring and inertial coefficient are incorrect. The current study shows that if the restoring moment is calculated precisely according to the section *Restoring moment coefficient*, by small adjustments in the value of the added mass coefficient, the damping coefficient value can be made proportionate to its surrounding points. An advantage of an NN is that it acts as a filter and does not create out-of-range data. The following steps must be taken to prepare the training data:

1. All the input values of coefficients should be calculated based on the equations in the section *Nonlinear roll artificial neural network structure*. Consider the constant value for the mass inertial coefficient, which is calculated according to the section *Moment of inertia coefficient*.
2. With a small change of about 5% in the constant added mass coefficient, the following considerations must be addressed:
 - The lowest number of points in which the damping coefficient is negative.
 - The range of damping coefficient changes is minimized for all points.

Neural network training

The deviation between the network output and the desired output is used to train the network, and the error function is calculated based on this deviation. The network weights must be set in such a way that the error function (Equation (14)) is minimized. Therefore, the weights are adjusted by the change in the reverse direction of the error function gradient. This method is called backpropagation. The following equations and schematic generally present the error backpropagation and weight adjustment (Jain, Mao, & Mohiuddin, 1996).

$$E = \frac{1}{2} \sum_{p=1}^l (d_p - z_p)^2 \quad (14)$$

$$\Delta \omega = -\eta \frac{\nabla E}{\nabla \omega} \quad (15)$$

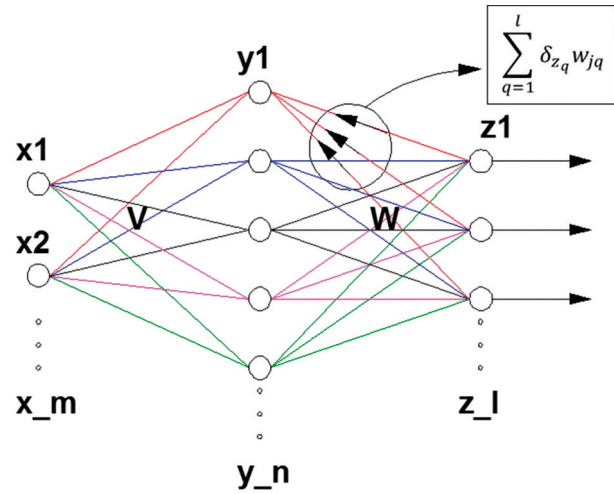


Figure 5. The error backpropagation method and weight adjustment

The equations of the weight adjustment of the output layers are as follows:

$$\Delta w_{ij} = -y_i \delta_{z_j} \eta \quad (16)$$

$$\delta_{z_j} = (d_j - z_j) f'(z_j) \quad (17)$$

In equation (14), d_p is the desired value, and z_p is the network output. The equations of the mid-layers are as follows:

$$\Delta v_{ij} = -x_i \delta_{y_j} \mu \quad (18)$$

$$\delta_{y_j} = f'(y_j) \sum_{q=1}^l \delta_{zq} w_{jq} \quad (19)$$

μ and η are the training coefficients that lead the training, so that all the training samples undergo change, and the training for the last samples is better than the previous samples. These coefficients reduce the training percentage, which is calculated as the mean. The reduction in the training coefficients in the final stages of training leads to getting close to the objective. In the momentum method (Equation (20)), a weight adjustment is made based on the means of some of the latest samples.

$$\Delta \bar{W}_{ij}(t+1) = -\eta \frac{\partial E(t+1)}{\partial W_{ij}} + \alpha \Delta \bar{W}(t) \quad (20)$$

Simulation and validation

The simulation and training of the network were carried out in two phases. In the first phase,

the network training was based on the test results in the IIHR laboratory at the American University of Iowa. The conducted tests were related to the roll decay, and the ship's model started moving at different speeds in a towing tank with an initial roll angle (Irvine, Longo, & Stern, 2004). This experiment was conducted for different speeds and initial rolling angles. In the current study, the ship's time-domain response was used. Regarding the fact that the oscillation was free and there were no waves, there were no roll exciting moments.

The RK4 method was used for solving the motion differential equation and the simulation of the roll motion. For the simulation, MATLAB Simulink software was used. The NN was placed in this signal diagram as a box and provided the equation coefficients based on the input response values. The differential equation was solved based on these coefficients. Figures 6 to 8 show the ship's roll response with respect to time. As seen, the simulated roll motion had good consistency with the test data.

For validation of the NN results, the maximum values of the rolling angle, the reduction amount in each oscillation, and the period of each swing were compared to the test results. These parameters are presented in Figure 9.

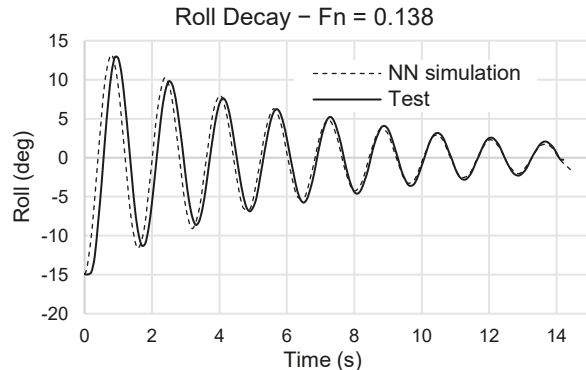


Figure 6. Roll motion simulation with a Froude number of 0.138

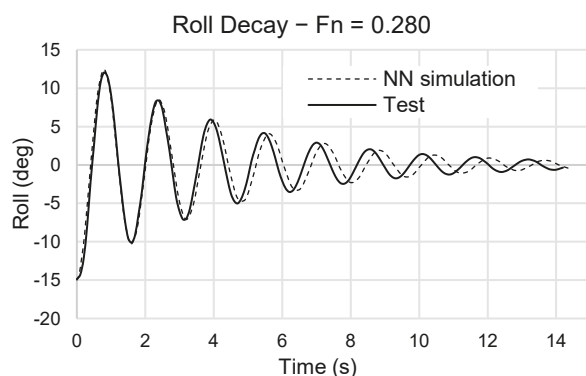


Figure 7. Roll motion simulation with a Froude number of 0.280

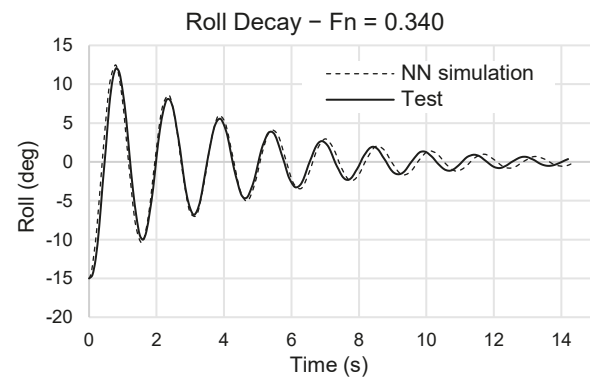


Figure 8. Roll motion simulation with a Froude number of 0.340

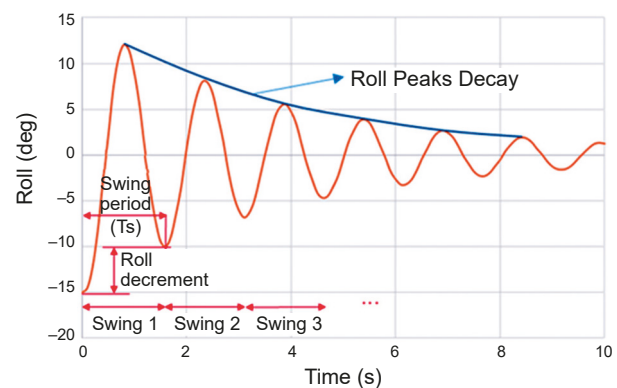


Figure 9. Roll motion validation parameters

The values of the roll peaks are presented in Figure 10. The accuracy of the peak values is essential in the simulation because in the control and roll stabilizer systems the primary control signal and the righting moment are generated based on the peak values. In addition to the peak values, the prediction of the corresponding time is important in the simulation. The deviation between the real times for peak occurrence and the simulation times caused amplification of the roll motion instead of stabilization. In Table 2, the error percentage of the roll motion validation parameters are presented.

In Figure 11, the roll decrement for each swing is presented. The value of roll decrement in each swing depends on the damping force. The test and simulation results are close to each other, meaning that the neural network correctly estimates the damping coefficients.

In the second phase, the network was trained based on the ship's response data in the irregular waves. The initial weights' conditions in the network were based on the trained neural network in the previous phase. The wave conditions, ship's speed, and heading angle were based on Table 3. These data were obtained based on numerical simulation (Mousavi, Khoogar, & Ghassemi, 2020). Numerical

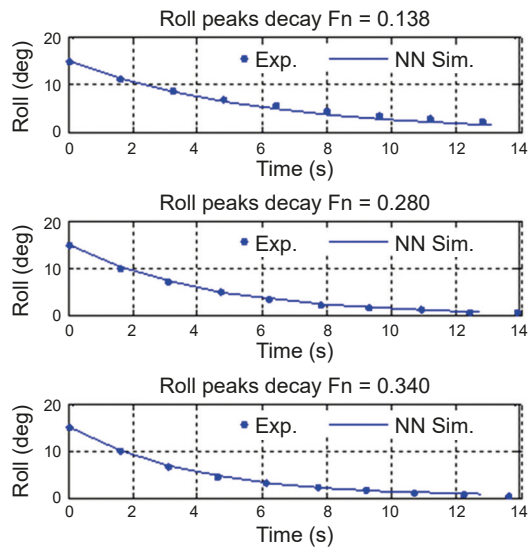


Figure 10. Roll peaks decay

Table 2. The mean error of simulation, compared to the test results, for the regular response

Froude No.	Average errors			
	Roll peaks	Roll peaks time (for 8 swings)	Swing period	Roll decrement
0.138	14.67%	0.2 s	2.36%	12.59%
0.280	4.56%	0.07 s	3.39%	3.08%
0.340	7.24%	0.1 s	5.22%	5.02%

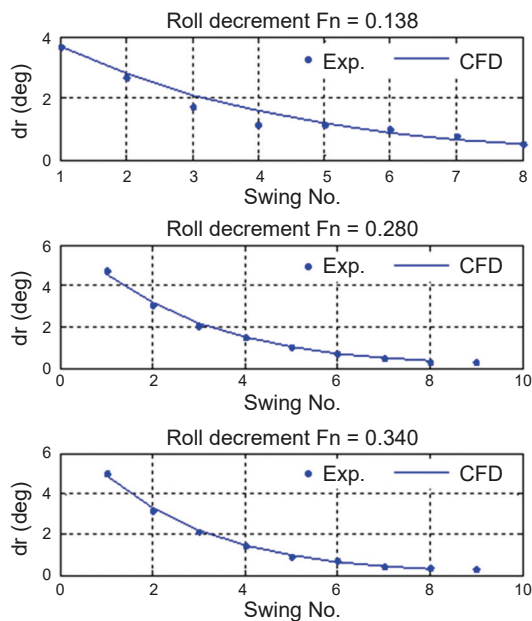


Figure 11. Roll decrement

Table 3. Simulation irregular condition

Heading speed (knot)	Heading angle (degree)	Irregular wave parameter	
		Significant wave height (m)	Modal period (s)
20	10	3.28	9.146

simulation has been verified in this reference, but the numerical result accuracy is not important, and the main goal of this section is to show that the trained neural network can trace the roll motion and can predict the dynamic coefficient in irregular waves. In practical use, the NN, training will be modified using the error between the ship's real motion and the predicted motion (NN results).

Figure 12 shows the ship's roll time history response in irregular waves. Figure 13 shows the exciting moment applied on the ship in the direction of roll with respect to time. Figures 14 and 15 show the ship's pitch and heave time response. Figure 16 shows the network training error. The network reached an error of lower than $1 \cdot 10^{-5}$ after 1115 calculation periods. Figure 17 shows the downward gradient for the weights and coefficient of momentum.

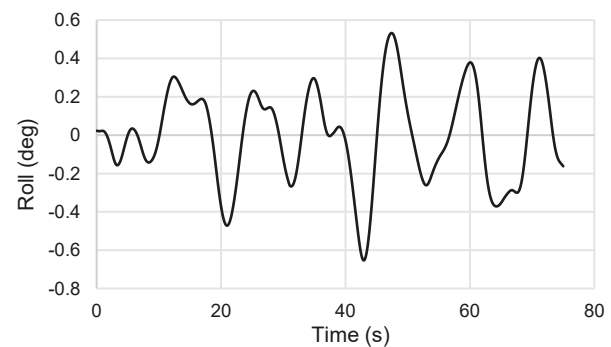


Figure 12. Ship's roll time history

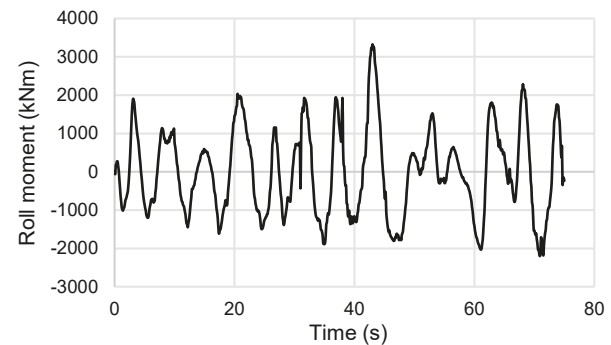


Figure 13. Ship's roll moment time history

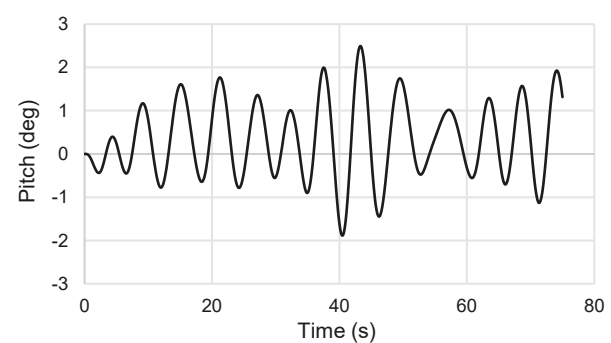


Figure 14. Ship's pitch motion time history

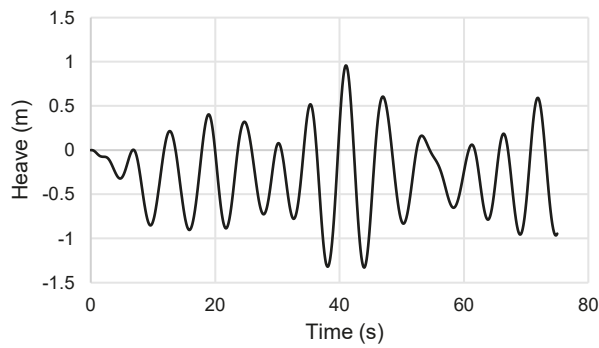


Figure 15. Ship's heave motion time history

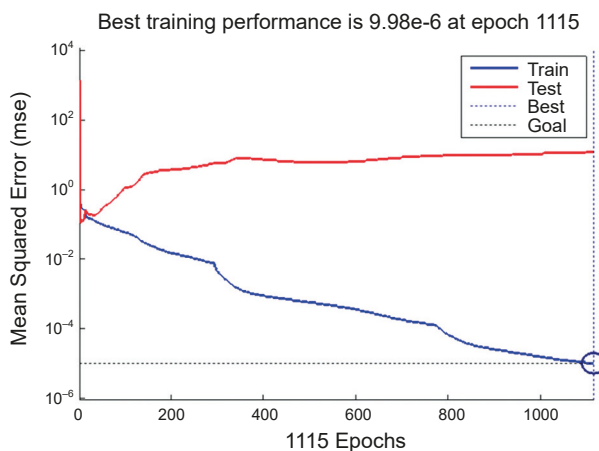


Figure 16. Network training error

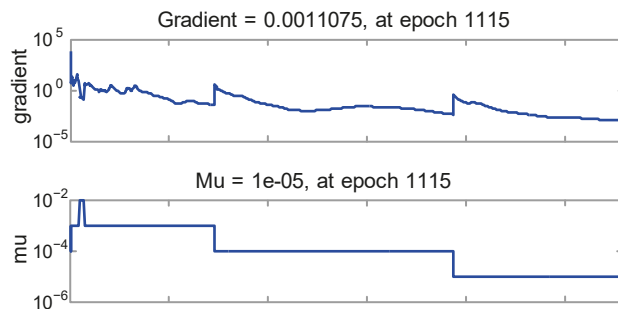


Figure 17. Error function gradient and momentum coefficient

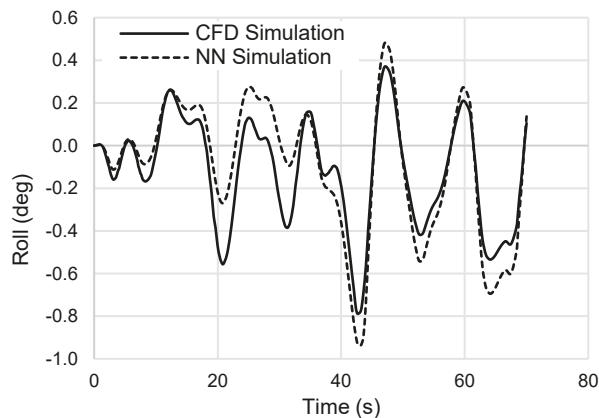


Figure 18. Comparison between the results of the NN and the CFD simulation of roll motion

The results of the roll motion simulation were compared to the initial results in Figure 18. The results of the NN simulation had a 20% average error compared to the numerical solution results.

Conclusions

In the current study, the definition of the nonlinear roll equation with consideration for the degrees of freedom of heave and pitch was carried out using a feed-forward artificial NN. The first phase was based on the roll decay test, and the second phase was based on the data obtained from CFD simulation in irregular and oblique waves. Preparation of the training data is very important, and these data must have an appropriate range so that the training is carried out correctly. Empirical equations were used in the current study for controlling the range of the coefficients.

In many cases, testing the ship in an oblique wave with heading angles is not possible since the tests are time-consuming and costly. Also, the simulation with the CFD method is difficult and complicated. In this study, after the NN initial training based on the roll decay test, the network was used for training and simulation in irregular and oblique waves. The network was able to simulate to a good approximation and was not sensitive to the new conditions. The NN was stable when the environmental conditions suddenly changed, and it could be used as a robust system.

In the current study, the pitch and heave motions were among the inputs of the NN, and their effects on the damping coefficient were considered. The NN involves nonlinear mapping, and precise achievement of this mapping is only viable through more accurate input variables that are more consistent with reality.

The NN itself acts as a powerful filter for the elimination of the out-of-range data, and it prevents divergence. The NN, in addition to having acceptable accuracy, has low sensitivity to condition changes. Another advantage of the NN is its high speed, which is an effective factor in controlling motion in waves and designing control systems.

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Material and Mechanical Engineering

Comparison of selected models useful in ranking the root causes of explosions in marine engine crankcases

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JEL Classification: L62, L90, L92, R41

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Abstract

This article aims to compile, describe and compare three different models taken from the literature describing the causes of explosions in the crankcases of marine engines. Each of the models has a different level of detail and was prepared with a different purpose. However, the same process, explosions in crankcases, was analyzed in all cases. A statistical evaluation of the frequency of events leading to explosions, a model built using failure mode and effects analysis (FMEA) and a model based on fault tree analysis (FTA) are described in turn. The FTA model drawn from the literature formed the basis for further analysis. Values of important measures of all elementary events of the fault tree were calculated using the Birnbaum reliability measure, Vesely-Fussell measure, Birnbaum structural measure, criticality measure and improvement potential. The percentage importance values of all events determined using these importance measures were compared. The results obtained from the application of each model were evaluated. The results of the models were compared with each other, and an approach using all three models supplemented with diversion analysis was proposed.

Introduction

System analysis methods are divided into inductive and deductive. Inductive methods (bottom-up methods) are based on a detail-to-general approach, i.e. analysis from the bottom (base events) to the top (peak events), while deductive (top-down methods) are based on the opposite approach, i.e. from top to bottom.

Inductive methods are used in determining the states of the system that may exist; they are usually used in the preliminary analysis of system

performance. Deductive methods, on the other hand, lead to the development, based on general knowledge, of special cases, to the search for root causes – events whose combinations lead to the occurrence of the postulated situation (state of the system) (Chybowski, 2017).

Deductive methods in relation to problem scenarios are referred to as root cause analysis (RCA) methods, and they help in the in-depth analysis of a problem by leading from the general to the specific, i.e. from the assumed postulated state of a system to the events that may occur during its operation,

the combination of which leads to the occurrence of a certain state of the system. An event is defined as any change in the structure or functioning of an object, while a state is the set of all characteristics of an object at a given moment t .

RCA methods follow an established workflow that consists of the following steps:

1. Define the problem.
2. Gather data.
3. Identify potential causal factors.
4. Identify the root causes of the problem.
5. Draw conclusions and give recommendations.

Among the most used methods of analysis aimed at assessing hazards and risks during the operation of industrial facilities are the tools shown in Table 1.

The methods listed in Table 1 can provide qualitative evaluation (descriptive characteristics, often derived from the analyst's individual experience and historical data) and/or quantitative evaluation (they use specific measures such as the probability of damage or operator error). Quasi-quantitative methods, on the other hand, use scales to provide quantitative information to rank individual events by importance.

The different methods have their own advantages and disadvantages and a dedicated range of applications, as shown in our selection of three models presented in the literature that can be used to assess the root causes of disasters.

One of the most dangerous events that can occur during the operation of marine engines, an explosion

in the crankcase, was chosen as the target of analysis and modelling.

Sequence of events leading to crankcase explosions

For a description of the circumstances leading up to crankcase explosions, see (Chybowski, 2022). A temperature rise is required to initiate an explosion, which can be either general, when the entire crankcase is affected, or local, in the form of a so-called hot spot (Włodarski, 1998). When crank-piston components are damaged, such as by galling of the main bearing, or when contact is made with a heat source located outside the crankcase (a fire in the sub-piston space or in the power plant), vaporization of the oil in contact with the hot spot occurs when the temperature exceeds about 200°C (Valčić, n.d.). Evaporating oil circulates in the crankcase (Burgoyne & Cohen, 1954). As oil vapor enters the cooler areas inside the crankcase, it condenses, forming a so-called white oil mist, with droplets having a diameter in the range of 5–10 μm . As a result of the abovementioned process, the concentration of oil mist increases to the level of the lower explosive limit, which is 47 mg of oil per 1 dm^3 of air (in some studies this level is specified as 50 mg/dm^3). This corresponds to an oil mist concentration of about 13% by weight. The phases of oil mist concentration change are shown in Table 2.

Table 1. A comparison of system analysis methods

Designation	Method of analysis	Deductive (Top-down)	Inductive (Bottom-up)	Quantitative	Quasi- -quantitative	Qualitative
5 Whys	5 whys method	+				+
AFD	Anticipatory failure determination	+		+		
ETA	Event tree analysis		+	+		+
FMEA	Failure mode and effects analysis	+	+		+	–
		(functional)	(hardware)			
FMECA	Failure mode, effects and criticality analysis	+	+	+	+	–
		(functional)	(hardware)			
FTA	Fault tree analysis	+		+		+
HAZID	Hazard identification	+				+
HAZOP	Hazard and operability study	+				+
What-if?	‘What-if?’ analysis	+				+
–	Subversion/sabotage analysis	+	+		+	+
–	Ishikawa diagram (Fishbone diagram)	+				+

Table 2. Phases of development of explosive mixture in the crankcase (prepared on the basis of (Islam, n.d.; Schaller Automation, 2015))

Specification	Phase I	Phase II	Phase III
Phase characteristics	Normal operating condition	Emergency	Lower explosive limit exceeded
Oil mist concentration [mg/dm^3]	< 1.99	1.99–47	> 47

When the oil-air vapor mixture reaches the ignition temperature, combustion is initiated, and an explosion occurs. Studies have shown that ignition can occur at 270–330°C and over 400°C (Islam, n.d.; Piotrowski & Witkowski, 2005).

The flame front travels along the crankcase, causing a pressure wave in front of it. The speed of the gas pressure wave in the initial phase is 0.3 m/s, increasing to about 300 m/s. In the case of long crankcases, it can reach up to 3 km/s (Chybowski, 2022). The maximum pressure in the crankcase during an explosion without detonation reaches about 7 bar (0.7 MPa). A properly designed crankcase should withstand a static pressure of 12 bar (1.2 MPa) without damage (Islam, n.d.).

The process of mixing oil vapor with air is intensified by the turbulence associated with crank-piston components and the operation of the explosion isolation valve (Valčić, n.d.). If, due to the venting of gases through the explosion isolation valves, the pressure in the crankcase is reduced below the pressure in the engine room (Valčić, n.d.), fresh air from the engine's surroundings will be drawn into the crankcase through the open explosion isolation valves (Freeston, Roberts & Thomas, 1956), which in turn can cause a secondary explosion that is more violent than the primary one and can cause further damage to the engine's surroundings.

If the explosion isolation valves do not work, the side hatch flaps in the crankcase wall will be torn out, and there is a risk of a secondary explosion (Rattenbury, 2002). A secondary explosion can also be caused by the failure of components in the crank-piston system (Chybowski, 2022). In this case, it is not preceded by a primary explosion, and is caused by the loss of continuity of the crankcase wall, resulting in a sudden influx of fresh air (BSU, 2018; MAIB, 2018).

Selected models of the causes of explosions in crankcases

A literature review was conducted on attempts to model the causes of explosions in crankcases. The methods employed were based on two main sources of data: statistics on historical damage and errors that could have led to the occurrence of explosions, and expert assessment, which was also based indirectly on information on historical events of a similar nature (Herdzik, 2019). Three of the most reliable techniques, which were based on recognized methods, were selected and analyzed in terms of assessing the causes of disasters and selecting the most

likely events that could have led to an explosion. An analysis based on statistical information, a model based on the FMEA method and a model based on FTA are presented. The latter two were supported by expert analysis and the use of fuzzy set theory. The data presented in this article have been posted in the ZENODO repository (Wiaterek & Chybowski, 2022).

Statistical evaluation of the incidence of explosions with a specific cause

By virtue of their design, trunk piston engines are prone to hot gas and fuel blow-by from the combustion chamber into the crankcase in the event of malfunctioning or damaged piston rings, pistons or cylinder liners (Chybowski, 2022). The components separating the crankcase from the combustion chamber are the pistons and sealing rings. Hot gas blow-by into the crankcase can be both the cause of areas of increased oil evaporation and the initiator of ignition. An explosion can also be caused by oil entering the crankcase through a cracked piston bottom (crown). The potential risk of explosion is exacerbated by the possibility of fuel entering the crankcase, for instance from a malfunctioning injection apparatus (Chybowski, 2022). As a substance with a lower flash point than oil (minimum 60°C), fuel can contribute to an explosion that would not have occurred without its presence in the crankcase. To avoid such situations, the engine's circulating oil is subjected to periodic laboratory analysis, especially for viscosity and flash point. Figure 1A shows the root causes of crankcase explosions of unshielded engines according to Rattenbury, developed based on the results of explosions that took place between 1990 and 2001.

In crosshead engines, there is no direct blowing of hot gases from the combustion chamber into the crankcase. Between these locations is the sub-piston space and/or air accumulator and the lower cylinder

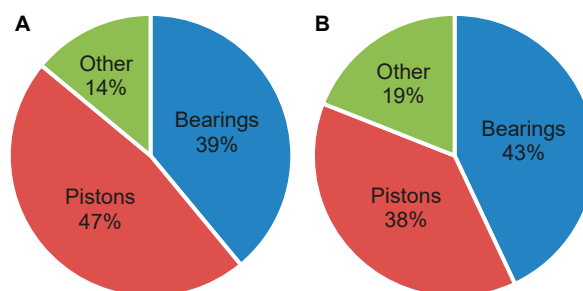


Figure 1. Causes of crankcase explosions according to Rattenbury (Rattenbury, 2002): A – trunk piston engine, B – crosshead engine

block plate (Chybowski, 2022). The piston stems are sealed in the wall with a gland. Figure 1B shows the root causes of crankcase explosions of unshielded engines according to Rattenburry, developed based on the results of explosions that took place between 1990 and 2001.

In a crosshead engine, unburned cylinder oil and combustion residues dripping from the cylinder liners accumulate in the sub-piston spaces (Chybowski, 2022). If the drainage system is not fully serviceable, and if periodic cleaning of the sub-piston spaces and the air reservoir is not implemented, a fire and/or explosion may occur in these spaces because of hot gas blowing from the combustion chambers, on principles analogous to those of trunk piston engines.

Bearing failures can have a variety of causes relating to both improper lubrication (oil flow too low, oil temperature too high or oil contamination), as well as the wear of plain bearing journals and liners, mechanical displacement of half-liners in the seat, and improperly performed repairs (failure to follow repair schedules or the use of non-original replacement parts) (Chybowski, 2022). The specific causes of plain bearing damage can vary depending on the type of engine, operating conditions, liner types used, etc. Examples of damage statistics for marine engine plain bearings are shown in Figure 2.

In crosshead engines, the cause of a crankcase explosion may be an increase in the temperature of one or more piston stems. The reason may be a fire in the sub-piston space, which, if not quickly extinguished, can contribute to a general rise in temperature in the crankcase and/or the formation of hot spots in the gland areas of the piston stems and the piston stems themselves. In addition, leaking piston

stem glands provide an additional source of heat in the crankcase in this situation (Chybowski, 2022). A separate risk is a malfunctioning piston stem seal (excessive blowouts on the piston stem gland (Włodarski, 1998) or excessive friction between the piston stem and gland rings (Nowosad, 2009), for example, when non-original rings or springs are used).

FMEA analysis of crankcase explosions

Another model was proposed by Cicek and Celik (Cicek & Celik, 2013), based on the results of an FMEA that was conducted for crankcase explosion events. The purpose of FMEA is to consistently eliminate errors in the construction and operation of a product by recognizing the causes of the errors and applying appropriate ways to prevent them from occurring. In the case of FMEA, after specifying the object of analysis, an analysis of the causes of defectiveness and criticality of errors is carried out for the selected product or process (Herdzik, 2015). Reference (Cicek & Celik, 2013) selected the main root causes of crankcase explosions, defining a Risk Priority Number (RPN) as a determinant of the significance of a given event (Gawdzińska et al., 2017):

$$RPN = O \cdot S \cdot D \quad (1)$$

where: O – frequency of occurrence index, S – severity index, D – detectability index.

A summary of the results of the analysis by Cicek and Celik is shown in Table 3. Model inputs are presented in (Cicek & Celik, 2013). This model has been analyzed in detail in, among other publications, (Wang et al., 2017).

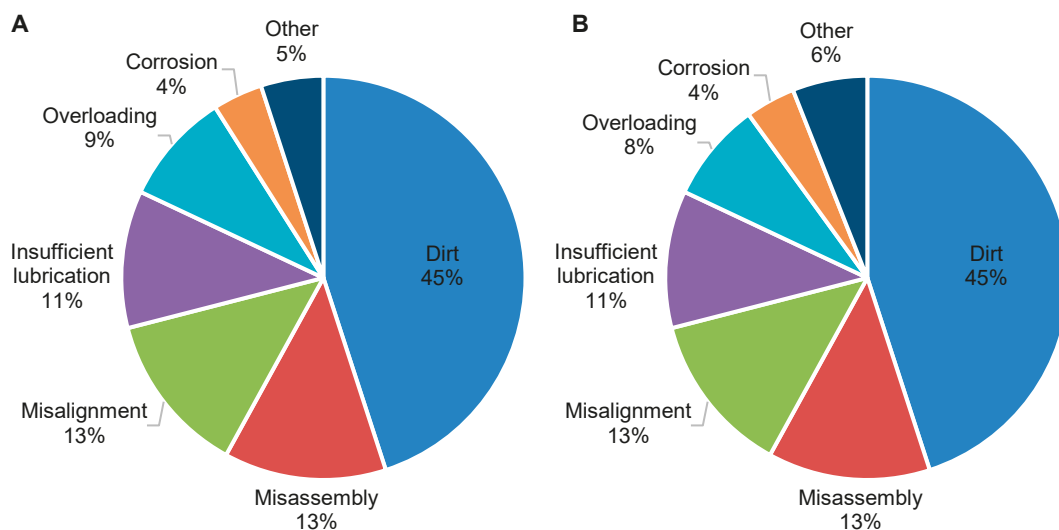
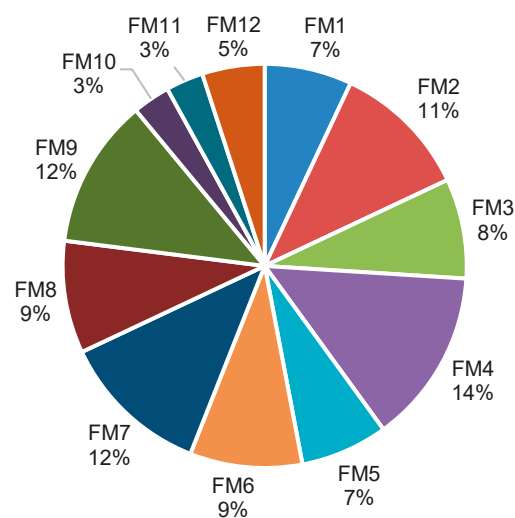


Figure 2. Percentage causes of plain bearing damage of internal combustion engines: A – according to Piaseczny (compiled from (Piaseczny, 1992)), B – according to Mahle (compiled from (Clevite, 2014))

Table 3. FMEA analysis worksheet (compiled from (Cicek & Celik, 2013))

Component	Failure mode	Failure causes	Failure effect	<i>O</i>	<i>S</i>	<i>D</i>	<i>RPN</i>
Oil mist detector	Inoperable (FM1)	Wrong calibration of oil mist detector	Oil mist in the crankcase cannot be detected	2	9	10	180
	Inoperable (FM2)	Lack of maintenance		4	9	8	288
Piston	Hole in the piston crown (FM3)	Dripping of fuel valve	Transmission of combustion gases into the crankcase	6	7	8	336
	Excessive wear on piston flame face (FM4)	Fuel impingement from poor atomization	Overheating and excessive pressure in the crankcase	7	8	7	392
Piston ring	Sticking to groove (FM5)	Deposits	Excessive clearance, fire blow	6	6	5	180
Stuffing box	Not functioning correctly (FM6)	Incorrect spring mounted in piston rod stuffing box	Transmission of combustion gas from the combustion chamber into the crankcase	4	10	6	240
	Wearing out of packing rings (FM7)	Loss of sealing	Spark and blow-by	6	7	8	336
Fuel valve	Early opening of fuel valve (FM8)	Service pressure too light	Poor atomization and combustion, timing problems, power balance and temperature variations	6	7	6	252
	Dripping (FM9)	Oversized injection mechanisms	Sticking of piston rings in their grooves, fire blow	7	8	6	336
Engine performance monitoring system	Not fully functional (FM10)	No periodic checking of electronic cards	Unawareness of abnormal condition in combustion process	2	7	5	70
Main bearing	Failing to lubricate (FM11)	Low oil pressure	Friction and excessive heat	3	8	4	96
Crankcase relief valve	Inoperable (FM12)	Not appearing to perform as designed and not seated correctly	Allows air to pass into the crankcase	2	7	9	126

Based on the summary shown in Table 3, it is possible to draw conclusions about the relevance of individual failure modes, the importance of which is represented by the RPN values, that is, in terms of frequency, consequences and the risk of failure to detect the problem for each event. Figure 3 shows

**Figure 3. Percentage of individual risk priority numbers for each failure mode (prepared on the basis of (Cicek & Celik, 2013))**

the percentage of RPN for the analysis in question, assuming that the sum of all RPN for all failure modes corresponds to a value of 100%.

The analysis in this case applies to two-stroke engines, but with minor modifications it can be adapted to the specifics of the operation and design of a trunk type engine, so it is evaluated in this material through the prism of the general applicability of the model to the assumed range of applications – that is, in this case, for a trunk type engine.

FTA model of crankcase explosions

FTA is one of the most widely used deductive methods. The method is based on a graphical logical model of the combination of events (component failures, software errors, human errors and environmental impacts) that can occur during the operation of a complex technical system (CTS), the coincidence of which causes a specific undesirable situation modelled through a so-called peak event (Chybowski, 2017) (Figure 4).

In reference (Ünver et al., 2019), this method was used to analyse the root causes of crankcase explosions of a two-stroke, self-ignition trunk

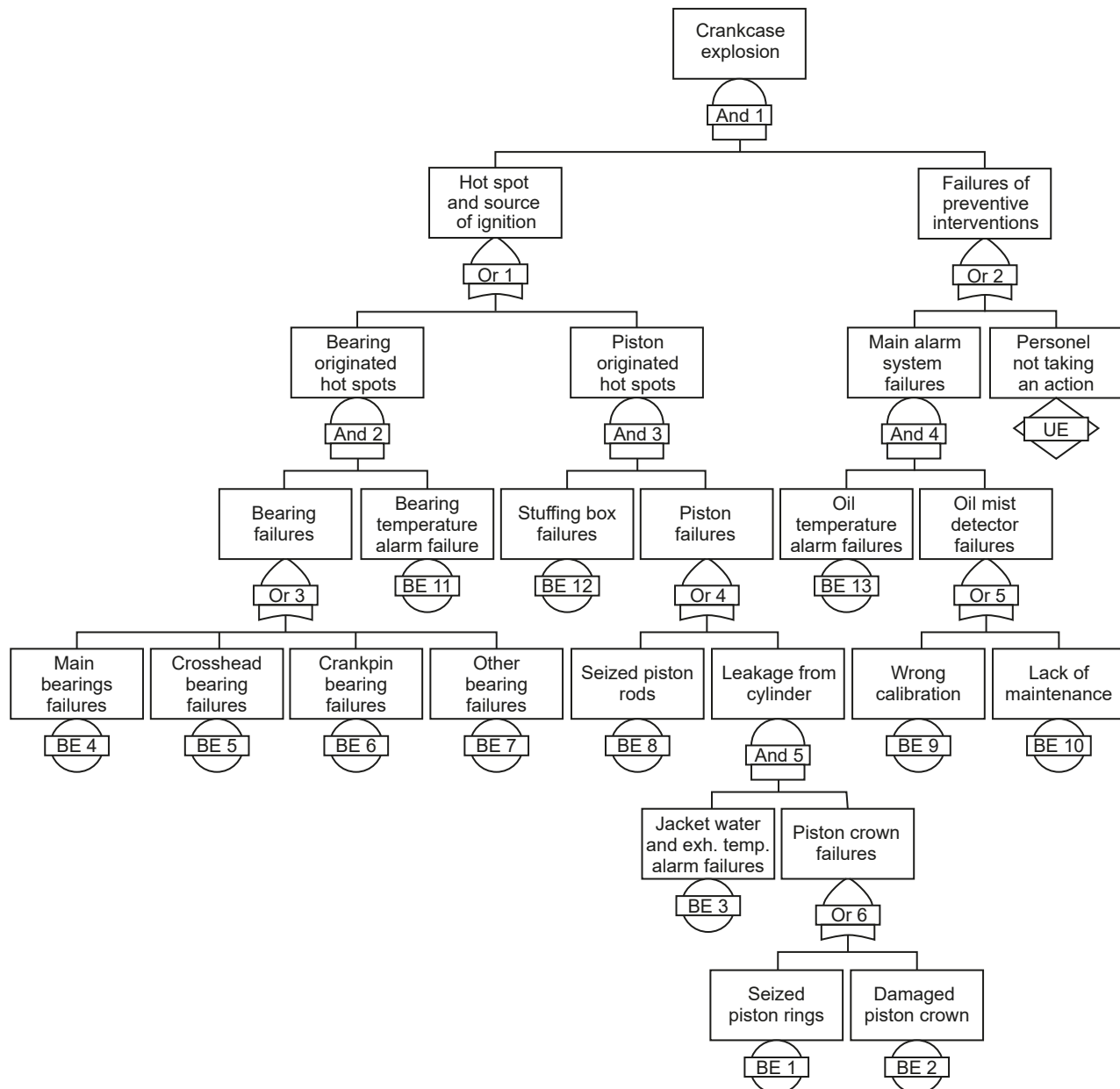


Figure 4. Fault tree for crankcase explosion of a two-stroke, trunk piston marine engine (prepared on the basis of (Ünver et al., 2019))

piston engine, including determining the probability of a peak event, the probabilities and validity of minimum cut sets, and determining general guidelines for preventing such disasters. The analysis in question was carried out in a fuzzy environment. With minor modifications, the fault tree can be adapted to analyses the explosion of crankcases in trunk piston engines. The original model taken from (Ünver et al., 2019) was used for further significance analysis of individual events performed in CARA-FaultTree Application 4.1. academic version (Sydvest, Trondheim, 2000), as shown in Figure 4, while Table 4 summarizes the individual elementary events and the estimated values of their probabilities of occurrence.

The model above can be used to determine the significance of individual events and their impact on the occurrence of a crankcase explosion. For this purpose, the values of the basic importance measures, i.e. Vesely-Fussell measure I^{V-F} , Birnbaum structural measure I^{Bs} , Birnbaum reliability measure I^B , criticality measure I^C and improvement potential I^P , were determined for each of the identified elementary events. Individual definitions of these measures and their detailed description are provided in the subject literature (Chybowski, 2014, 2020; Chybowski, Idziaszczyk & Wiśnicki, 2014). The calculated values of each measure are summarized in Table 5.

To visualize the contribution of each event to the occurrence of the peak event (crankcase explosion)

Table 4. Characteristics of primary events in the analyzed fault tree (prepared on the basis of (Ünver et al., 2019))

Event	Description	Event probability
BE1	Seized piston rings	0.002931
BE2	Damaged piston crown	0.000299
BE3	Jacket water and exhaust gas high temperature alarm failure	0.001858
BE4	Main bearing failure	0.001958
BE5	Crosshead bearing failure	0.001036
BE6	Crankpin bearing failure	0.001137
BE7	Other bearing failure	0.000699
BE8	Seized piston rods	0.000601
BE9	Wrong calibration of the oil mist detector	0.002525
BE10	Lack of maintenance of the oil mist detector	0.003740
BE11	Bearing high temperature alarm failure	0.002239
BE12	Stuffing box failures	0.002239
BE13	Lube oil high temperature alarm failure	0.002972
EU	Staff not taking an appropriate preventative action after an alarm	0.010169

and their mutual comparison, the pie charts shown in Figure 5 were used.

The charts describe the percentage of events due to their importance (the sum of the importance of all events is 100%). Analysis of the values obtained for all measures showed that particularly significant events affecting the occurrence of a peak event were BE 11 (bearing high temperature alarm failure) and UE (personnel not taking an appropriate preventative action after an alarm).

Conclusions

Each of the models presented provides different information, due to factors such as different assumptions. The level of decomposition of the explosion process in the engine crankcase leads to different observations on the frequency of participation and importance of individual events on the incident of explosion.

The statistical description is the most general in this case, although individual events could be further examined in more detail (decomposed). However, this model, due to the lack of analysis of the interrelationships between events, reduces the assessment of significance to an analysis of the frequency of individual events (serial reliability structure model). An event is therefore more important the more often it occurs under the operating conditions.

The quality of the FMEA model depends largely on the assumptions made, the available source data and the experience of the experts who are part of the team conducting the analysis.

The FTA model describes the logical relationships between events, so it represents the best of the models described in the article in terms of relationships and process structure. Thus, it can be used to assess the validity of events. It seems that linking the FTA model to statistical data can be a good solution for obtaining meaningful results from statistical analysis. In addition, the results of the validity analysis can be used in the next step to determine the severity index in the FMEA analysis.

It should be noted that all three models described in the article cited from the scientific literature do

Table 5. Estimated values of the importance of each primary event

Event	I^B	I^{V-F}	I^{Bs}	I^C	I^P
BE11	0.0000498060	0.8897300	0.4229700	0.8895600	0.0000001115
BE8	0.0000228090	0.1091800	0.1141400	0.1093500	0.0000000137
BE4	0.0000227430	0.3557000	0.0281980	0.3552100	0.0000000445
BE6	0.0000227240	0.2065500	0.0281980	0.2061000	0.0000000258
BE5	0.0000227230	0.2004900	0.0281980	0.2000400	0.0000000251
BE7	0.0000227140	0.1269800	0.0281980	0.1266500	0.0000000159
EU	0.0000123050	0.9981700	0.4071000	0.9981700	0.0000001251
BE12	0.0000061836	0.1102700	0.2511000	0.1104400	0.0000000138
BE13	0.0000000762	0.0018277	0.2442600	0.0018064	0.0000000002
BE3	0.0000000736	0.0010902	0.0684810	0.0010910	0.0000000001
BE1	0.0000000423	0.0009893	0.0228270	0.0009900	0.0000000001
BE2	0.0000000422	0.0001009	0.0228270	0.0001007	0.0000000000
BE10	0.0000000361	0.0010911	0.0814210	0.0010773	0.0000000001
BE9	0.0000000361	0.0007366	0.0814210	0.0007264	0.0000000001

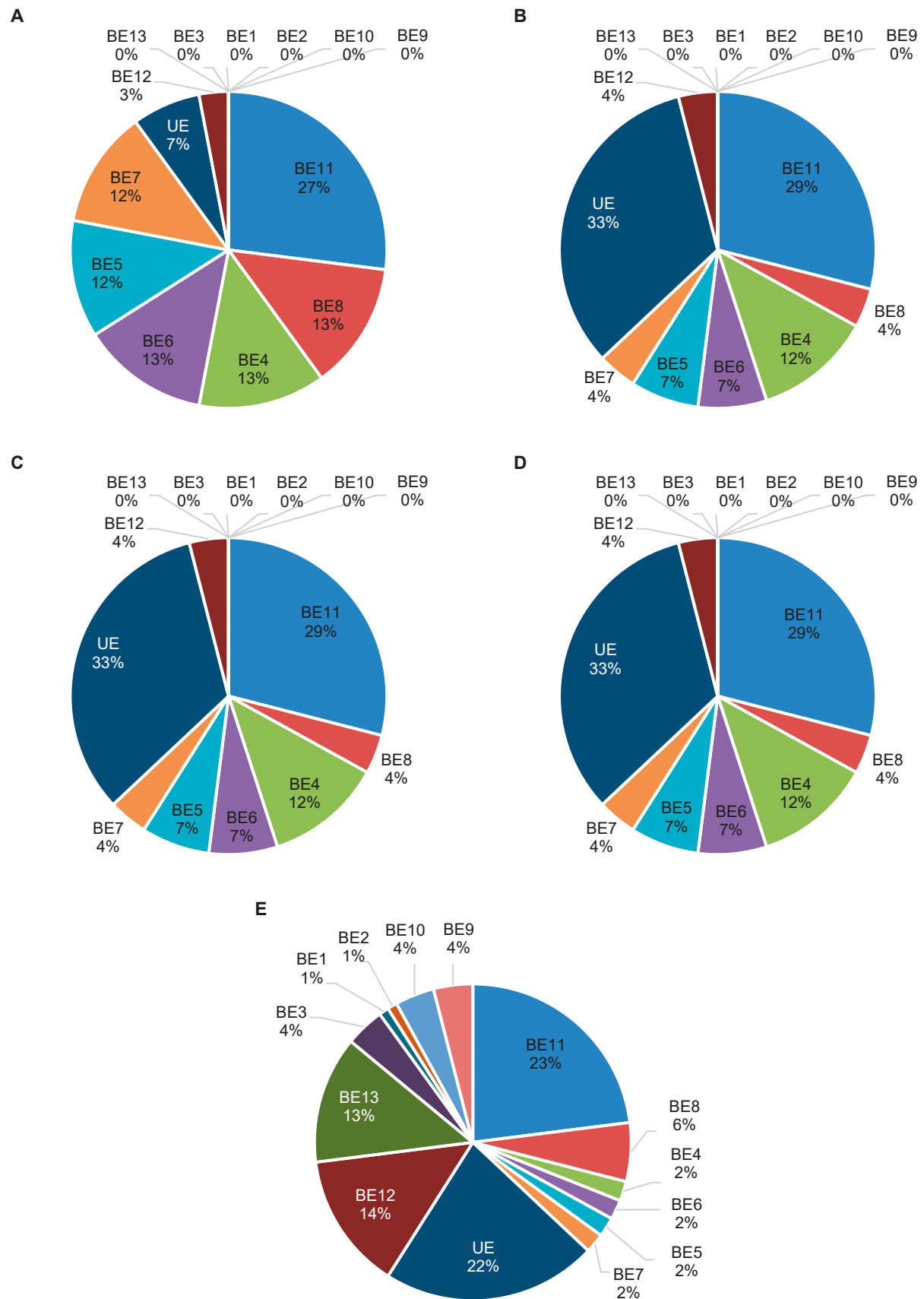


Figure 5. Percentage values of importance measures of events leading to explosions in the crankcase: A – Birnbaum reliability measure, B – improvement potential, C – Vesely-Fussell measure, D – criticality measure, E – Birnbaum structural measure

not capture (or capture only indirectly – by merging several primary events) some events that can lead to explosions in the crankcase, such as a fire in the engine room or a fire in the sub-piston space. To search for root causes in depth and refine the FTA or FMEA model, it is advisable to use tools aimed at finding hidden causes of damage and intentional damage to the system. An example of such a method could be the analysis of diversion (sabotage). The authors believe that linking diversion analysis, statistical data, FTA and FMEA would enable the most objective results possible to be obtained when assessing the risk of operations and planning countermeasures to prevent a disaster from occurring.

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Iron impact on the quality of sand casting made from secondary AlSi7Mg0.6 alloy used in the automotive and aerospace industry

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Abstract

Due to the high demand for secondary alloys in the automotive and aerospace industry, this work investigates the effect of higher iron content on the quality of AlSi7Mg0.6 sand castings. Secondary-recycled Al-Si alloys contain an increased amount of impurities due to their remelting of scrap metal. One of the most unwanted impurities found in these alloys is iron. Iron leads to the formation of various Fe-rich intermetallic phases, whose morphology influences the mechanical properties even at low Fe content. It also promotes the formation of casting defects, such as porosity and shrinkage. The formation of porosity in secondary Al-alloys is another major aspect that can affect the final properties of castings. Since these materials are mainly used to produce castings for the automotive industry, such as engine blocks, cylinder heads, and so on, it is necessary to produce castings without any defects. Therefore, the quality of AlSi7Mg0.6 sand casting is investigated at lower iron content (0.128% wt. Fe) and compared to the higher iron content (0.429% wt. Fe), whereby a correlation between iron content and porosity is monitored.

Introduction

Nowadays, the automotive industry has a key role in the economy of developed countries. Regarding the latest trends in automobile manufacturing, the main priority is to implement the principles of lightweight construction to meet customer demands, reduce gas emissions and fuel consumption, and optimize mechanical performance. For these reasons, it is necessary to perfectly match the choice of materials to the operating life of the components (Tisza & Czinege, 2018; Bogdanoff et al., 2021).

The environmental and economic advantages of secondary-recycled aluminum alloys make them the best candidate materials for various applications in different industries, such as automotive, construction, aerospace, etc. Secondary Al-alloys are made from aluminum scrap and recyclable aluminum waste by recycling. Aluminum can be recycled repeatedly without loss of its properties. The high value of aluminum scrap is a major incentive and economic impetus for recycling. Remelting the Al-recycled material saves almost 95% of the energy consumption required to produce primary-ore

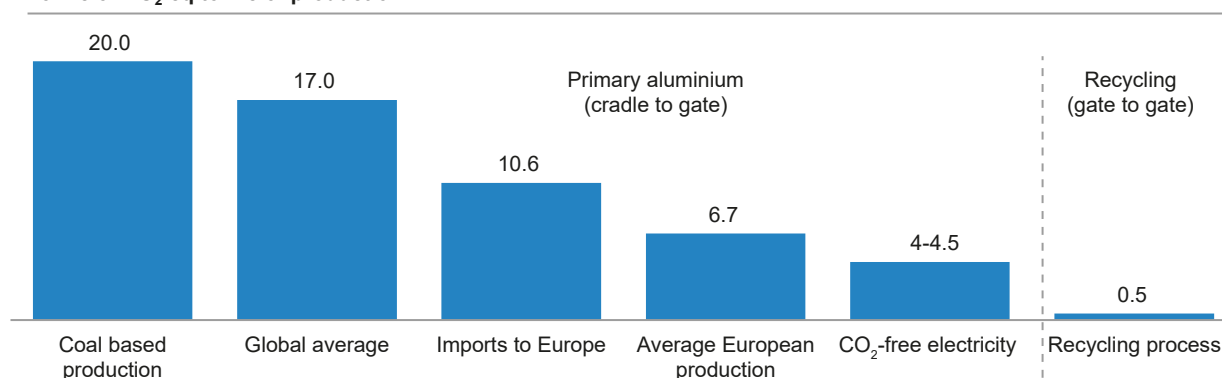
Tonne of CO₂-eq/tonne of production

Figure 1. Greenhouse gas emissions of primary aluminum production and recycling process (World Aluminum, 2015)

aluminum, thus avoiding corresponding emissions, including greenhouse gases as depicted in Figure 1 (Song et al., 2022; Tillová, Chalupová & Kuchariková 2012).

Al-Si-based alloys are the most widely used types of foundry Al-alloys. The quality of secondary Al-Si alloys is considered a key factor in alloy selection casting for a specific engineering application. Due to lightweight, fluidity, castability, fabricability, high strength-to-weight ratio, low density, good corrosion resistance, etc., castings from secondary Al-alloys have applications in a wide range of industries. However, their use in the transport sector has become increasingly rapid (Figure 2). Heat-treatable Al-Si-Mg alloys, in particular, are widely used to produce automotive castings such as cylinder blocks, steering knuckles, cylinder heads, valve lifters, pistons, and so on (Tillová, Chalupová & Kuchariková, 2012; Svobodova, Lunak & Lattner, 2019; Kuchariková et al., 2020; Abdelaziz et al., 2022; Li et al., 2022).

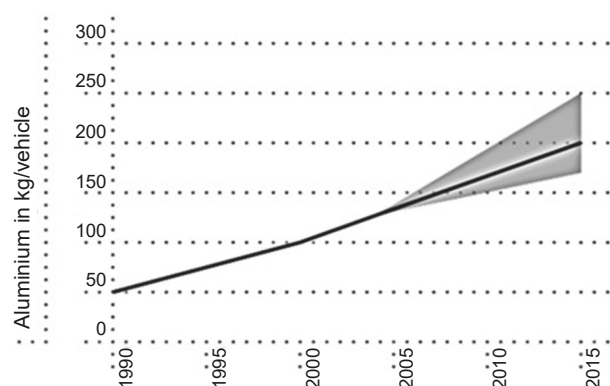


Figure 2. Aluminum content in European vehicles (EAA/OEA, 2006)

Improving the mechanical properties and structure of Al-alloys can increase the life of the casting.

To achieve optimal mechanical properties, various elements such as Ni, Mg, Cr, Mn, and Zn are added to the melt. However, the unavoidable elements that act as impurities seriously reduce the complex mechanical properties of secondary Al-alloys. A significant problem with many of the unavoidable co-elements is the complicated process of eliminating their negative effects on Al-Si-Mg alloys. In most cases, they cannot be removed under foundry conditions. Therefore, their content needs to be reduced to an acceptable limit (Farkašová, Tillová & Chalupová, 2013; Bacaicoa et al., 2019; Song et al., 2022).

Due to the increasing production of secondary Al-castings, it is necessary to ensure strict metallurgical quality control (Farkašová, Tillová & Chalupová, 2013; Hirsch et al., 2022). This is because the quality of this casting is influenced by the higher presence of Fe. The recycling process leads to an accumulation of Fe from impurities in bauxite ore and from contamination of scrap aluminum by ferrous metal. Fe cannot be easily removed from the melt by conventional foundry treatment; only dilution seems to be practical, via an uneconomical method to reduce its Fe content in the alloy. Fe is also the most harmful impurity in recycled Al-Si alloys with low solubility in Al-alloys, formed as an intermetallic phase. Among the Fe-rich phases, the most significant in Al-Si-Mg alloys are the β -Al₃FeSi (β -Fe) and α -Al₁₅(FeMg)₃Si₂ (α -Fe) phases. The β -Fe phase is very harmful due to its three-dimensional platelets or fragile two-dimensional needle-like morphology. It is well-known that the presence of the Fe-phase affects the increased formation of porosity and shrinkage due to the large Fe-needles preventing the melt flow, which causes the presence of shrinkage pores. In addition, the investigation by Brueckner-Foit et al. (Brueckner-Foit et al., 2017) proved the damage mechanism in a secondary alloy of shrinkage pores, found on the

inner side of the specimen, acted as primary crack initiation sites.

Many authors reviewed techniques to neutralize the detrimental effects of Fe by the addition of elements such as Mn, Co, Cr, Be, and Sr. Mn is a widely used element to remove the harmful Al_5FeSi phase. Mn addition of up to half the amount of Fe leads to the formation of a less harmful shape $\alpha\text{-(Al}_{15}\text{(Fe,Mn)}_3\text{Si}_2)$, with a skeleton-like or Chinese-script-like morphology that does not initiate cracks (Taylor, Caceres & Crepel, 2008; Bacaicoa et al., 2019; Svobodova, Lunak & Lattner, 2019; Tillová et al., 2019; Song et al., 2022).

Unfortunately, Al-Si-Mg alloys are susceptible to extensive porosity, not only for higher Fe content but also due to the decreasing solidification rates in sand molds. Unlike alloys cast into metal molds that quickly solidify and refine dendritic cells owing to their excellent ability to transfer heat. Another disadvantage of sand molds is that castings made in metal molds are usually more ductile than those made in sand molds (Mae et al., 2008; Kasala et al., 2011; Davor, Špada & Ilkic, 2019; Fiocchi, Biffi & Tuissi, 2020; Reyes et al., 2020).

Since a high amount of Fe can negatively affect the quality of aluminum castings by forming porosity, it is imperative to minimize its content and, thus, reduce its negative impact because porosity is still the most critical problem. Therefore, this study investigates the quality of AlSi7Mg0.6 sand casting with a consideration of structural defects caused by different Fe content.

Experimental material and procedures

An experimental material was used: secondary AlSi7Mg0.6 (EN AC 42 200, A357) cast alloy produced by Uneko Ltd., Czech Republic. Three alloys were cast with different Fe content: A (0.128% wt. Fe) and B, C (0.429% wt. Fe). The addition of Mn (0.149 wt. %) was intentionally added to alloy C in the form of a pre-alloy AlMn75, with the aim of investigating the Mn effect on structural components. From the alloys (A, B, C) were cast experimental bars with dimensions $\phi 20$ mm and length of 300 mm, into sand molds by a gravity casting method. The casting temperature was 750°C, and the refining temperature was 740–745°C. The ECOSAL AL 113S salt was used as a refining salt. Experimental bars were heat-treated according to the T6 method. The heat treatment of T6 was carried out at UNEKO, s.r.o. and consisted of a dissolution annealing at 530°C $\pm$ 5°C with a holding time of 7 hours.

Rapid cooling to 50°C was then followed by artificial aging at 160 °C for 6 hours. The chemical composition of the experimental alloys, according to the delivery list, is shown in Table 1.

Table 1. Chemical composition of AlSi7Mg0.6 alloys [wt. %]

Alloy	Si	Fe	Cu	Mn	Mg	Ti
A	6.742	0.128	0.012	0.046	0.519	0.108
B	7.097	0.429	0.013	0.044	0.466	0.119
C	6.881	0.429	0.011	0.149	0.596	0.103

In alloys: Ni (< 0.002), Cr (< 0.002), Pb (< 0.005), Sn (< 0.003), Na (< 0.006), Sr (< 0.002), Al (rest)

The experimental alloy AlSi7Mg0.6 is commonly heat-treated to improve its strength properties. After heat treatment, it becomes one of the strongest sand-cast secondary Al-Si-Mg alloys, widely used to produce frames, brackets, housings, and other automobile parts.

Samples used for metallographic evaluation were cut from the experimental bars using an MTH MICRON 3000 automatic saw with water cooling applied to avoid heating effects and deformation of the microstructure. After the cutting, the samples were prepared by standard metallographic procedures (wet-ground on SiC papers, polished by a Struers Op-S, and etched by 0.5% HF and 95% H_2SO_4 to highlight the Fe-rich phases). After each operation, the samples were rinsed with warm water, ethanol, and then dried with hot air.

Prepared samples were observed by using an optical microscope Neophot 32 and a scanning electron microscope (SEM) VEGA LMU II. A quantitative analysis was performed by using the image analyzer NIS Elements 4.0 to numerically evaluate porosity and the size of the pores. The resulting average values were calculated from a minimum of 15 measurements.

Results and discussion

The representative microstructures of experimental A, B, and C alloys are shown in Figure 3, which corresponds to the typical hypoeutectic microstructure consisting of primary $\alpha\text{-Al}$ dendrites, eutectic (mixture of $\alpha\text{-matrix}$ and spherical grey Si-particles), and intermetallic Fe- and Mg-rich phases, primarily concentrated in the inter-dendritic areas. The needle-like Al_5FeSi phase was present.

Increased Fe content leads to the formation of longer Fe phases in the form of plates/needles in alloy B compared to alloy A. Therefore, it is confirmed that, with increasing Fe content, the presence

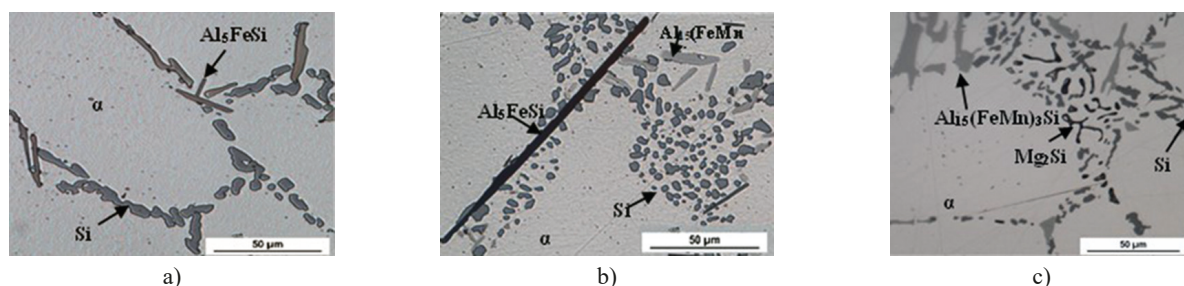


Figure 3. Microstructure of AlSi7Mg0.6, etch. 0.5% HF: a) alloy A, b) alloy B, and c) alloy C

of Fe needles and their length ascend as well. With the increased amount of Mg in alloy C, it was possible to also observe the intermetallic phase Mg_2Si intermetallic phase in the form of fine spheroidized black particles (depicted in Figure 3c). From Figure 3, it can be proved that the addition of Mn into alloy C has a positive effect on the transformation of needle-like Al_5FeSi into a less harmful skeletal $Al_{15}(FeMn)_3Si_2$ intermetallic phase. Additionally, it can be observed that the heat treatment led to the spheroidization of the eutectic silicon, which is not in the form of plates (Kucharikova, Tillová & Chalupová, 2016) but in the form of spheroidized particles (Figure 3).

From the average porosity results in Table 2, for alloy C, in which Mn was intentionally added, the area fraction of the pores was the largest. The largest average pore sizes were also measured in alloy C. The smallest average pore sizes were in alloy A, with the lowest Fe content, and their size increased with a growth in the Fe content. These results correlate with the research of Taylor et al. (Taylor, Caceres & Crepel, 2008), who investigated the effect of Mn

in a higher Fe-alloy on the porosity of castings; they concluded that the presence of Mn does not guarantee an improvement in the porosity. Manganese appears to reduce the higher amount of porosity associated with an increased Fe content, primarily in Cu-containing Al-Si alloys or at the correct $Fe/Mn = 2/1 = 0.5$ ratios (Table 2). Increased porosity in alloy C (Table 2), with the addition of Mn, is possibly related to the low Mn content added to the correction of the β -phase, displayed in Table 1.

The evaluation of the porosity and pore sizes show that the pores are in close contact with the Al_5FeSi needles, shown in Figure 4. This pore formation confirmed the investigations of Puncreobutr et al. (Puncreobutr et al., 2014) and Brueckner-Foitz et al. (Brueckner-Foitz et al., 2017) that Fe-needles

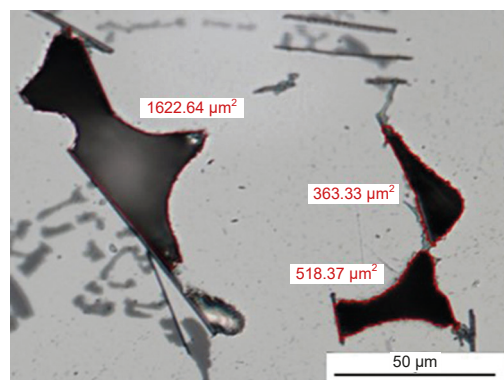


Figure 4. Pore formation surrounding the Al_5FeSi needles in an AlSi7Mg0.6 alloy B, etch. H_2SO_4

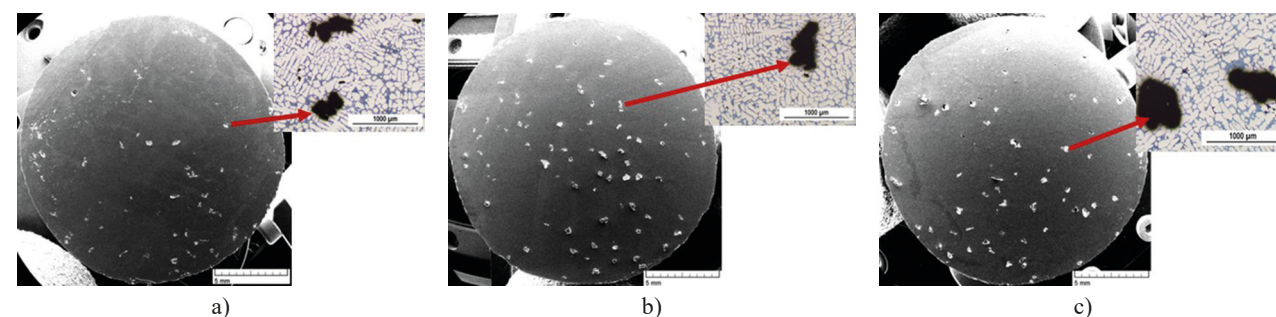


Figure 5. Macrographs of the cross-section of the AlSi7Mg0.6 alloys etch. 0.5% HF: a) alloy A, b) alloy B, and c) alloy C

are surrounded by pores and act as nucleation sites for porosity. Therefore, the alloy with the highest content of Fe (i.e., alloy C) has the highest porosity.

The SEM surface macrographs are in Figure 5; it shows the distribution of the pores of the investigated alloys. The porosity in the experimental alloys A, B, and C was observed to be directly proportional to the % Fe. In alloy A, with 0.128 wt.% Fe (Figure 5a), sponge-shaped pores were observed mainly in the center of the casting. For alloys B and C with 0.429 wt.% Fe, the pores appeared to be distributed over a larger area (Figure 5b, c) and locally large pores are found at the edge of the casting.

Summary and conclusion

The results of the quantitative analysis proved the impact of iron on the quality of sand castings from AlSi7Mg0.6 alloy as follows:

- The quality of experimental alloys is significantly affected by Fe-rich phases, which promote the formation of casting defects such as shrinkage pores.
- In experimental alloys A, B, and C, mainly Fe-rich intermetallic phases were present, the needle-like β -Al₅FeSi. Another type of Fe-rich phase, skeletal, or Chinese script-like α -Al₁₅(FeMn)₃Si₂ phase was also present in alloys B and C. In all the alloys, the Mg₂Si phase was identified in the form of fine spherical particles.
- With increasing Fe content, both the porosity and the average pore size grow, most of the pores being surrounded by Fe-rich phases.
- The addition of Mn positively affects the transformation of needle-like β -Al₅FeSi to skeletal α -Al₁₅(FeMn)₃Si₂. On the other hand, Mn negatively affects the porosity in alloy C (0.429 wt.% Fe). With the addition of 0.149 wt.% Mn, both the porosity and the average pore size significantly increased, probably due to the low Mn content added for the correction of the β -Al₅FeSi.

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Environmental Engineering and Mining

Verification of the deposit model and determining the course of the fault in the entire rock mass

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Abstract

This article presents results for the development of new methods of inserting discontinuity lines into the numerical model of the deposit in CAD systems. The main problem in creating a numerical model of the deposit is usually a very small number, as well as low reliability of the source data. Hence, the authors developed new algorithms for inputting discontinuities, which can be used in particular for conditions when a large number of discontinuities are present. The article offers algorithms for inputting discontinuities into the entire deposit model. The method of transferring faults from the higher seam to subsequent seams and determining the course of the fault in the entire rock mass has been described. The fault can be represented as a spatial mesh of triangles, just like the seam floor. Then the fault can be extended until it intersects with the next seam (with the next triangle mesh) using geostatistical methods. As a result, we determine the exact position of the discontinuity line in the next seam. The paper also presents several algorithms for checking the deposit model made using the methods developed by the authors, including the analysis of outliers (in terms of elevation and inclination), testing the variability of the fault throw, checking the distance between adjacent seams, and verifying the position of the deposit in relation to the existing workings and boreholes. It should be noted that the key issue while building a deposit model is a checking of the model, removal of the assumptions and, obviously, incorrect data in order to obtain the highest possible accuracy.

Introduction

When creating a numerical model of a deposit, one of the most important problems we face is the insertion of discontinuity lines. The problem is particularly important when there is a dense mesh of discontinuity lines and the amount of data allowing for their input is limited. Therefore, in order to enable the implementation of this type of tasks, the Silesian University of Technology developed proprietary methods of inputting discontinuity lines into

the numerical model of the deposit, i.e., the method based on a calculation of the spatial position of the fault involving existing contours that reach it from both sides, which includes the assumption that the inclination of the seam in front of and behind the fault is constant, an implementation of the independent surface of the upthrow and downthrow side with the Kriging extrapolation method, the transfer of a fault from a higher lying seam or the Carboniferous strata, and the method of closed areas. These methods were implemented in the Geolisp program

within the CAD system (Geolisp, 2022). They are presented in detail in the article “Methods of introducing a discontinuity line into a numerical model of a hard coal deposit”.

Important works in this field was developed in different parts of the world: in China (Wu & Xu, 2003; Wu, Xu & Zou, 2005; Zhu et al., 2006; Jia, Li & Che, 2020), Pakistan (Jiskani & Siddiqui, 2019) and Poland (Jelonek, Poniewiera & Gąsior, 2015, Sokoła-Szewioła & Poniewiera, 2019). It should be noted that the problem is very complicated, and its solution depends most of all on the geological and mining conditions in a given area. It is of particular importance in the case of many years of underground mining operations, where data is available in the form of maps containing thousands of faults and hundreds of thousands of measurement points.

Accurate mapping of the entire deposit becomes extremely time-consuming. Hence, this article presents a procedure that significantly speeds up the construction of the model. It was proposed to adopt a solution in which a simplified model of the entire deposit is developed, while the areas of current and planned exploitation are developed with maximum available precision. The developed method is based on generating the surfaces of the underlying seams based on the surface of the first seam floor (including faults, folds, and other disturbances). The algorithm for carrying out this task is conducted in several stages. In the first stage, the surfaces of differences between the seams are generated, in the second stage, large faults are transferred to the next seams located below, and then small faults are transferred to the next seam.

The subsequent part of the article presents the scope for checking the deposit model, developed with the use of the algorithms proposed in the articles, with particular emphasis on the course of the inserted discontinuities. The checking includes an analysis of outliers (in terms of elevation and inclination), testing of the fault throw variability, checking of the distance between adjacent seams, and verification of the position of the deposit in relation to the existing workings and boreholes.

Research methodology

Determining the course of the fault in the entire rock mass

1. *Generating the surface of differences*

Seams are not at a constant distance from each other, they can merge in one place and disappear in

another. However, we have a series of geological boreholes and in each of them is the vertical distance between the seams. Based on this data, we create an area of triangles that allows for the determination of the distance between seams at any point.

It should be noted that some boreholes do not occur in all seams. In addition, we have elevation data points that appear only on one seam. For example, if a single floor elevation measured in the exploratory working lowers a given seam by a few meters, all seams from the top and bottom have to take this depression into account, otherwise they will cross. In order to properly create all the seam floor surfaces in the rock mass, virtual geological boreholes should be inserted, which will cause subsequent seams to be more or less parallel and will not intersect. When creating the surface of the differences, it should be noted that the seams may have different names in different openings, e.g., when the seam splits into several layers: 401/1, 401/2, 401/1 + 401/2, and 401. It is convenient to divide such a seam for two or three separate layers and its thickness in a given borehole spread equally between all layers.

Of course, all these activities involve inserting virtual boreholes and assigning thickness, and it must happen in a fully automated way and according to defined rules. This has to be so because new measurements are made every day in the operational mine, and the model of the deposit must be automatically updated in accordance with most recent information of the deposit.

The algorithm for generating the difference surface includes:

- Creating the surface of the first seam, preferably the one that is best recognized.
- Constructing the surface of the triangle for the differences between the next seam and the first seam. We extrapolate it to the border of the area and use the ordinary Kriging method. Each borehole is checked and also the elevation points in the current and following seam. If any data does not exist in the first seam, we calculate its value by adding an interpolated point from the surface of differences.
- Again, we generate the first seam taking into account the added borehole. Moreover, the next seam is created. These activities are repeated until all the boreholes have a complete set of floor elevation data for all seams.
- From the surface of the differences, the boreholes are removed which in the given seam are located inside the fault zone or on the other side of

the fault. Theoretically, we could include such openings by subtracting the throw of the fault from the elevation of the seam floor. However, but we know the fault throw only roughly and it is safer just to delete such a borehole. We must use the iteration for this – several times repeating the above-mentioned activities because the surface of differences is made in order to obtain the position of the fault. Only after its determination can we see which openings should be removed. Removing these boreholes changes the position of the fault and the whole procedure should be repeated.

- The added boreholes should be completed with a seam thickness. Based on all the openings in the given seam, the surface of thickness is made. We extrapolate it to the border of the area using the ordinary Kriging method. Where the borehole passes through the seam, we enter a thickness of 0.01 (we can zero this, but one centimeter does not change the calculations and at first glance we see that the borehole is added). However, where the borehole was not deep enough, we calculate the thickness based on the thickness surface.

2. Large faults transfer to the subsequent seams

Usually, the largest problem we have is the insertion of a fault into the first seam. The following procedure can be applied to all seams at the same time, although the authors propose to apply it for subsequent seams. The discussed algorithm is automated to a certain extent (Figure 1), the user does not perform all activities, however, some verification activities should be done manually on each seam separately.

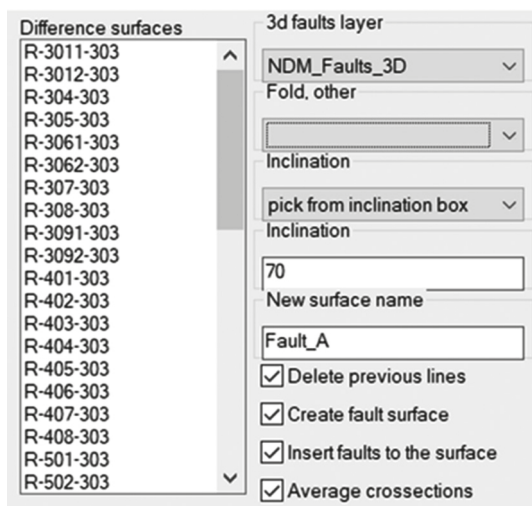


Figure 1. The application dialog box used to transfer faults to the subsequent seams

The algorithm of transferring the fault to the subsequent seams involves:

1. Texts and faults binding, so that descriptions and possibly other elements of the map move along with the movement of the fault lines on the map. In practice, in the described applications, this is done by inserting points at the ends of the selected objects, e.g., folds. Next, the program saves the position of such points relative to the faults and, after changing the position of the fault, it updates the location of the points and these objects.
2. Conversion of 2D faults into 3D, which means assigning elevation data to the lines on the numerical map. This can be completed using one of the methods presented in the article “Methods of introducing a discontinuity line into a numerical model of a hard coal deposit”. The result of such an operation is the seam floor surface containing faults.
3. Generate a dense network of seam floor isolines, e.g., with a 10 m pitch. They are not necessary for the correct transfer of the fault, but they facilitate all verification activities and allow for manual corrections to the created deposit model.
4. Move faults to the next seam. In practice, this means inserting a new line more or less parallel to the existing fault (precisely speaking to the trace of intersection of the fault with the first seam). The new line will mark the intersection of the fault with the next seam. The distance between the trace of fault in the first seam and the trace in the subsequent seam will depend on the inclination of the fault and the distance between the seams. The distance between the seams is different at each vertex of the fault line – it is calculated based on the distance surface, which is determined in point 1 – *Generating the surface of the differences*. The result of the program operations is shown in Figure 2.
5. Verification whether the fault lines pass through confirmed fault locations (i.e., in exploratory workings). If not, it means that the inclination

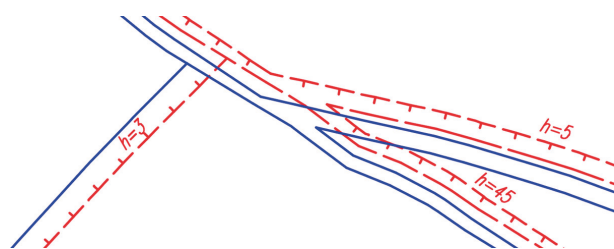


Figure 2. Red lines represent trace of the fault in the first seam, while the blue lines depict the fault intersection with the next seam

has been selected incorrectly (or there is another mistake, e.g., wrong fault throw). The new slope must be recalculated using the trigonometric functions, assuming a linear course between confirmed points. If data has been changed, activities described in point 4 must be repeated. In some seams, the fault disappears and splits into several smaller ones, it is then difficult to determine its position automatically. In this case, trace of the fault in the given seam must be inserted manually.

6. Verification of intersection points of new faults. The algorithm moves each fault separately and the result sometimes is not correct, especially if two faults are close to each other. In the lower seam they should merge into one fault, but the program will draw two intersecting lines. In this case it is required to review and correct the location of the fault intersections manually.
7. Move the isolines created at the stage described in point 3 to the new fault lines. Other lines like disturbances, folds, and seam merge lines should be moved too.
8. From the elevation of the objects obtained in point 7, we subtract the surface of elevation differences determined in accordance with the algorithm presented in point 1 – *Generating the surface of the differences*. As a result, objects such as isolines, folds, and faults intersection points receive the elevation of the subsequent seam.
9. The faults obtained in stage 4 are spatial lines; however, in practice it is better to recalculate them – from the isolines obtained in point 8 – using the existing contours method.
10. Create the surface of the seam floor taking into account all data, including isolines and faults created in the above paragraphs.
11. Verification of the faults throws, distances between neighboring seams, the inclination of each triangle, etc. (see next section). If, as a result of the verification, it turns out that there is a significant error in data, then the whole procedure starts from the beginning.
12. Moving descriptions of faults and other objects, as we planned in point 1.
13. Commence construction of the triangles surface of the next seam. The presented method may look complicated, but in practice the construction of the next seam does not take more than a few hours.

3. Small faults transfer to the subsequent seam

Large faults cross many seams, their course is reasonably predictable since the rock mass moves

along fairly steady surfaces. However, small faults sometimes occur only in one seam, disappear, and then re-appear in the lower seam. Rather, we can talk about a zone of a cracked rock mass, where the course of the fault cannot be predicted in any way. The decision on which fault is large, and which is small is arbitrary and depends on the geologist developing the deposit model. Usually, we define the limit value of the discharge, e.g., two meters, below which we consider the fault to be small. Yet, if a given fault occurs in several adjacent seams, we include it in the model even if the discharge is smaller than assumed. However, such faults cannot be completely ignored, because their occurrence is important information for engineers designing new exploitations. The procedures in this case may be as follow:

- Copy small faults to the next seam, as if they were vertical, then insert them at the same place as in the previous seam.
- Project these faults to the surface of the floor of the subsequent seam.
- Assign a zero fault throw value. It is not necessary to insert them into the deposit model. Inserting them unnecessarily complicates the model and increases the time required for all calculations. But on the other hand, we receive additional information in a spatial view; we see small triangles, so we can observe that something is happening in this position. In any case, we must remember that these faults must be transferred to all paper documentation.
- Small faults are transferred only to the nearest seam from their appearance. Only the large faults are transferred to the subsequent seams.

4. Presentation of the fault in the form of the surface of triangles and its extrapolation

The fault can be presented in the form of a surface of triangles, just like the seam floor. This is the most recommended method for controlling the model of the deposit. The way of creating and controlling the surface of the fault is presented in the next section. Just like the seam floor surface, the fault can be extrapolated using geostatistical methods.

Hence, the solution is to cross the surface of the fault with the seams generated based on geological boreholes. This method is simple and fast, the option “Insert faults to the surface” of the program (shown in Figure 1) works according to such a procedure.

The algorithm for finding the intersection of seams with a fault surface involves:

- Based on the boreholes, create a surface of triangles for each seam floor separately.

- Extrapolate these TIN surfaces to the boundaries of the mining using geostatistical methods.
- For each seam, create a volumetric surface area consisting of the surface of this seam and the surface of the fault.
- The intersection of the seam and the fault will overlay with the isoline zero of the volumetric surface.
- Find the second trace of the fault (the end of no deposit zone) corresponding to the method of extending the neighboring surface.
- Next, successively create TIN surfaces for the floor of all seams, each of them based on geological boreholes and both fault traces (Figure 3).

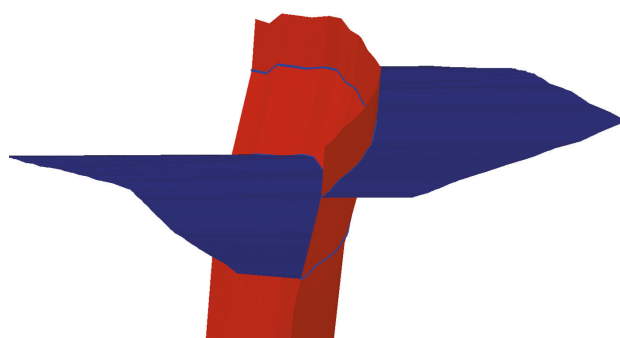


Figure 3. Intersection of a seam floor surface (blue) with the fault surface (red)

If a fault throw is unknown, it is determined from the following procedure:

- Insert a line between adjacent boreholes, one (A) inside the area where there is a lot of data, the second (B) outside of this area.
- Project this line to the seam floor surface created from data inside the main area. Using the linear interpolation method (if there is a lot of data, we can use geostatistical methods), extrapolate the elevation at the location of the borehole B. The difference between the actual elevation of borehole B and the one calculated will be the value of the fault throw in this position.
- Proceed similarly for the next pairs of geological boreholes along the entire length of the fault. We assume that the throw of the fault in the other cases bends between the boreholes calculated in the pair's changes in a linear way.

Verification of the deposit model

The scope of the verification includes the following stages:

1. Generating isolines of the seam floor. Analysis of the course of isolines to check whether they

overlay with the original isolines, are parallel to each other, reach a right angle at the fault, do not disturb near the geological holes, and the change of inclination is smooth (Figure 4).

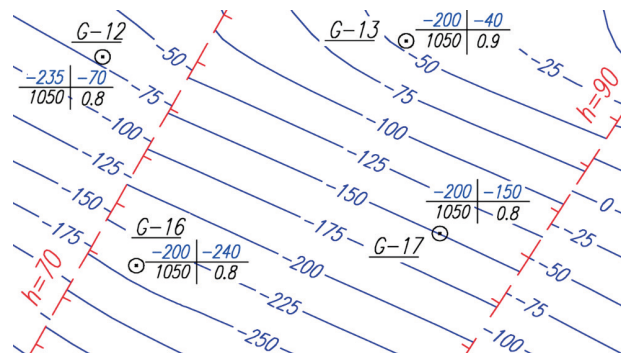


Figure 4. The course of the seam floor isoline next to the faults and boreholes

2. Prepare a series of cross-sections through a rock mass. On the cross-section, we can see if the subsequent seams cross or are parallel to each other. If the workings are located on the cross-section, it must be checked whether in these workings the passage through the coal seam was actually observed.
3. Check if the floor elevation of the triangles is exactly the same as the value from the borehole. The article omits issues related to the selection of surface smoothing coefficients using geostatistical methods. However, it should be mentioned that, for example, an incorrectly chosen nugget effect can cause the inclination of the seam to change rapidly near the borehole. It is easy to find out this error by analyzing the course of the contours near the borehole.
4. Generate a volumetric surface between each pair of seams. The isolines of the volumetric surface indicates the vertical distance between these seams. If there is an isoline of zero, it means that the surfaces intersect. The distance between the seams should not change rapidly, the isolines should be parallel to each other.
5. Create an additional surface of the triangles of the floor inclinations. Check every location in which the inclination of the seam has an unusual value. If the seam in a specific location has a very large slope, it usually means that we have not removed the triangle from the center of the fault.
6. Calculate the inclination of the fault line in the seam in each triangle separately. Changing the inclination of this line should be done in a smooth way. Similarly, check other lines that build the

deposit model, e.g., the fold axis or the seam merge line. The discussed software has the function of marking all locations in which the inclination is greater than is given.

7. Calculate the fault throw along its entire length. Similar, to the previous point, the change of the fault throw should occur in a proportional way. The software draws graphs of the change in the throw of the fault, which allows the wrong location to be quickly spotted (Figure 5).

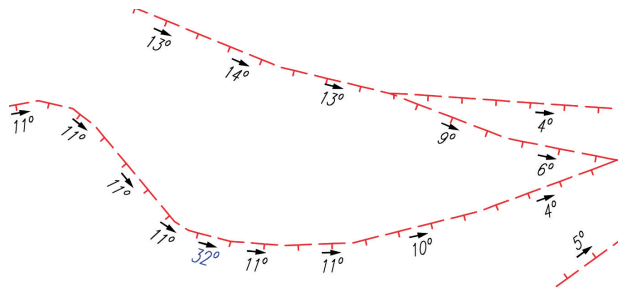


Figure 5. Graph of the change in the throw of the fault

8. Examine the model of the deposit and check the isometric view. Usually, it is possible to capture positions where, e.g., faults intersect in an unlikely way.
9. Check the floor surface near the boundaries of the developed area. If the surface of the seam floor is cut by faults, it cannot be extrapolated using geo-statistical methods. One of the possible solutions is an attempt to restore the surface from before the occurrence of tectonic movements. As a result of such an operation, we obtain one large surface, without faults, which we can extrapolate to the boundaries of the area, e.g., by the ordinary Kriging method. Verification consists in making a cross-section through a rock mass and checking the changes in inclination near the boundary of the area.

Discussion and conclusions

This article presents the problem of inputting a discontinuity line for the case of long-term underground exploitation of hard coal deposits, such as in the case of the Upper Silesian Coal Basin; in this area, industrial exploitation has been carried out since the 19th century. The time-consuming nature of developing a numerical model of the deposit under such conditions was indicated. A solution has been presented in which a simplified model of the entire deposit is developed, while the area of the

currently conducted and planned operation in the near future is performed with the maximum available precision.

It should be noted that the development of the floor of the first seam (containing the faults, folds, and other disturbances), from which we start building the model in the proposed solution, is presented in the article “Methods of introducing a discontinuity line into a numerical model of a hard coal deposit”. Next, in accordance with the proposed procedure, we create volumetric surfaces (TIN surfaces of distance differences) between all analyzed seams. Knowing the size of the fault throw and its inclination, fault traces for all the seams are determined. In the last stage, the course of small faults in the next seam is determined.

An absolutely key issue for the correct development of the deposit model, especially in the presence of the discontinuities, is the checking of the deposit model and the removal of assumptions and obviously incorrect data. It is true that the structure of the deposit is often very complicated, but it is recommended, however, to carefully inspect the model in such locations where sudden change in the fault throw or seam cut is observed.

This article presents the scope of the model checking, which includes activities enabling the verification of the correctness of the isolines course, the generation of a volumetric area between each pair of seams, the calculation of the fault inclination in the seam (separately for each triangle) and along its entire length, the verification of the position of the deposit in relation to the existing workings and boreholes etc.

It can be stated that the algorithms developed at the Silesian University of Technology allow for the insertion of discontinuity lines to the numerical model of the deposit in CAD systems. They make it possible to reduce the time-consuming nature of building such a model, while ensuring the highest possible accuracy of the model, with a specific range of data available. The authors presented a number of procedures that enable the control of the work performed to achieve a high accuracy of the model.

Future works on this solution may be related to a new heuristic architecture for production line management in JSW S.A. (Jastrzębska Spółka Węglowa) (Dyczko, 2021). The identified small amount of data to some extent confirms the thesis about the need to expand the scope of collected data in the mining map proposed in other works (Krawczyk, 2018).

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Health effects of long-term exposure to industrial dust in preparation plants of hard coal mines

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Abstract

Statistical data on occupational diseases registered by the Institute of Occupational Medicine in Łódź indicates a renewed increase in the number of pneumoconiosis in Poland in recent years, especially in the section of PKD (Polish Classification of Business Activities) – mining. Simultaneously, in 2018, because of the implementation of Directives of the European Parliament and the Council of the European Union, changes were introduced to Polish legislation in the field of protection of workers against the risk of exposure to carcinogens or mutagens related to the respirable fraction of crystalline silica formed during work. Considering this information, the members of the Department of Safety Engineering of the Silesian University of Technology attempted to assess the dust hazard and the frequency of occurrence of respiratory diseases among the employees of the preparation plant of mine X exposed to the harmful effects of industrial dust produced in the work process. The following methods were used as part of the research: individual dosimetry, infrared spectrometry, directional interview, diagnostic tests, and spirometry. The obtained results made it possible to identify workstations with the highest exposure to the harmful effects of industrial dust and to recognize the impact of this action in the form of pathological changes in the respiratory system in 18.4% of the miners surveyed.

Introduction

The report of the Central Register of Occupational Diseases (Świątkowska & Hanke, 2021), published in 2021 by the Institute of Occupational Medicine, shows that in 2020 1850 new cases of occupational diseases were recorded in Poland. The most frequently diagnosed cases of occupational diseases in this period were infectious or parasitic diseases or their sequelae. In total, 505 such cases were

recorded, which constitutes 27.3% of occupational diseases diagnosed in 2020 in Poland. Interestingly, this group also included 38 cases of Covid-19 for the first time, which had not been recorded before. The second group of diseases in terms of the number of reported cases were pneumoconiosis – 490 cases (26.5%, occupational pathologies), which since 2018 (392 cases) have recorded a steady increase of over 25%. Among the diagnosed cases of pneumoconiosis in Poland in 2018–2020, pneumoconiosis

of miners of mines dominates – 774 cases (58.0% in this group), asbestosis – 279 cases (20.9%), and silicosis – 239 cases (17.9%). These three disease entities account for 96.8% of all pneumonia recorded in the last three years in Poland. The highest incidence per 100 thousand employed in 2020 was recorded in mining (276.3 cases), education (23.3 cases), agriculture and forestry (18.0 cases), industrial processing (16.9 cases), as well as healthcare and assistance social (13.0 cases). Occupational incidence rates among mining workers have remained at a very high level for years (2018 – 184.5 cases and 2019 – 216.4), almost ten times higher than in the next group of socio-economic activities, i.e., education (9.6), and 18 times higher than the average in Poland. It is disturbing that despite the decline in employment in recent years in the mining industry by nearly 3.5 thousand employees (2018 – 91,014 employees and 2020 – 87,566), the incidence of pneumoconiosis in the same period increased by 49.8% (WUG, 2021).

Among the harmfulness and nuisances of the work environment, recognized as the main causative factor of occupational diseases according to the Institute of Occupational Medicine in Łódź, industrial dust is also mentioned the most frequently (36.7% of occupational diseases), including dust containing asbestos and hard coal and lignite dust containing free silica. In addition to various types of pneumoconiosis ($N = 490$ for 2020), industrial dust was indicated as a factor that contributes to the development of pleural diseases, asthma, allergic rhinitis, and extrinsic allergic alveolitis.

Exposure to industrial dust is also the most common cause of malignant neoplasms, which is considered an occupational disease. Among 193 cancers diagnosed in 2018–2020, 164 cases (85%) were caused by asbestos dust, and 36 (18.7%) by dust containing free crystalline silica. These types of dust are responsible for 106 confirmed cases of lung cancer and all cases of mesothelioma (67). Although the total number of occupational diseases in Poland has decreased in recent years, the incidence of pneumoconiosis is growing. The leader in this respect is traditionally the Śląskie Voivodeship, where over 50% of all cases of pneumoconiosis in Poland are recorded each year. This regularity is related to the structure of the industry in the Śląskie Voivodeship and the highest percentage of people employed in the mining industry in the country.

Therefore, the increase in the number of cases of this disease is worrying, especially as they are often chronic diseases that significantly impact health, and their development may take years. Hence, early

detection of disease symptoms and prompt initiation of treatment have the greatest impact on the course of the disease and its possible consequences. Too late of a diagnosis of a patient's ailments may have dire and irreversible consequences for saving health. That is why such an important element in the fight against this group of occupational diseases is to take appropriate preventive measures to reduce the presence of dust at the workplace and to cover employees at risk of industrial dust with the appropriate medical prophylaxis, especially in mines and mining plants extracting hard coal, where these diseases are the most numerous.

Employees of the Department of Safety Engineering at the Silesian University of Technology, together with students at the Pomeranian Medical University in Szczecin and specialists in the field of pulmonology, attempted to assess the actual working conditions in the zone of harmful dust exposure in the preparation departments of mine X to meet the expectations mentioned above. These studies were combined with the voluntary medical examinations of miners. The innovation of this research method allows for more precise verification of the causes and health effects of occupational pneumoconiosis, which so far was most often diagnosed based on disease symptoms in the advanced stage without examining the causes and properties of the dust that caused it.

Literature review

Despite many international efforts and actions taken (López-Campos, Soler-Cataluña and Marc Miravittles, 2019) to limit the exposure of hard coal mine workers to contact with harmful dust generated in the mining process (Liu & Liu, 2020), tens of thousands of miners around the world are still exposed to its harmful effects (Laney & Weissman, 2014). The result of this exposure is pneumoconiosis (Barber & Fishwick, 2016), common among miners with acute-fibrotic and chronic-insufficiency (Han et al., 2018), which for years has been the subject of research and scientific publications by many researchers from Columbia (Torres Rey et al., 2015), the Czech Republic (Tomášková et al., 2017), Poland (Brodny & Tutak, 2018), Asia (Perret et al., 2017), Australia (Zosky et al., 2016), the United States of America (Hall et al., 2019), and other industrialized countries of the world.

To reduce the risks in mining excavations of hard coal mines, in addition to personal protective equipment provided to employees exposed to

dust-generating processes, technical solutions are also used. This limits the amount of dust generated or deprives it of its volatile properties. Among the most effective technological solutions that should be mentioned are the following:

- ventilation systems (Bałaga et al., 2015; Ji et al., 2016);
- sprinkling systems mounted on the heads of mining machines (Bałaga et al., 2016; Lutyński, 2021);
- water curtains installed in mining excavations (Bałaga, 2019; Peng et al., 2022);
- dedusting devices (Kuczera & Ptaszyński, 2019; Xu & Wang, 2021);
- rock mass irrigation (Zhang et al., 2022; Liao et al., 2021).

Taking care of the health and life of employees is one of the basic obligations of the employer, resulting directly from the Labor Code (ISAP, 1974) and other industry legal regulations. Actions to effectively prevent occupational diseases can be divided into three categories.

The first one is primary prevention, i.e., care for the work environment, occupational health and safety (Tobór-Osadnik, Wyganowska & Manowska, 2017), and other activities aimed at creating safe working conditions. This purpose is served by properly conducted environmental measurements of dust at the workplace and occupational risk assessment (Mocek, 2002), which enable effective preventive measures to reduce the occurrence of dust hazards (Krzemień & Mocek, 1999; Korban, 2019). The second is promoting knowledge about work safety (Korban, 2015), persuading employees to change their behavior, and shaping the desired attitudes in employees (Wyganowska, 2019). All of which result in a real improvement in working conditions and conscious action to protect one's own health (Biały, 2012, p. 17).

The third should be appropriate medical prophylaxis, enabling ongoing monitoring (Ergün et al., 2017) of the health of the workers most exposed to harmful dust, preventing the diseases or detecting it as early as possible (Zhang, 2021). Therefore, in addition to the periodic environmental measurements required by law, employers should also provide employees with access to medical care allowing for regular and more frequent health checks (Yang et al., 2017) and, thus, fulfilling the provisions of article 101 Regulation of the Minister of Labor and Social Policy of September 26, 1997 on general provisions on health and safety at work and article 222 of the Labor Code.

Methodology

Research on the health effects of long-term exposure to industrial dust in the selected preparation plant of mine X was performed by employees of the Department of Safety Engineering of the Silesian University of Technology, in cooperation with employees of the Central Laboratory for Work Environment Research "Stanisław Bielaszka" in Jastrzębie Zdrój and physicians in the field of pulmonology. As part of the research, in accordance with the regulations in force in Poland (ISAP, 1997; 2011; 2018), the following were carried out:

- 1) Measurements of dust concentration in the inhalable and respirable fractions at the workplace.
- 2) Measurements of chemical substances concentration at workplaces.
- 3) Prophylactic diagnostic tests of the respiratory system of employees of selected preparation plants.

To determine the concentration of dust from the inhalable and respirable fractions at the workplace, samples taken at the workplace were used based on the following:

- PN-Z-04008-7:2002 *Air purity protection – Sampling. Principles of air sampling in the work environment and interpretation of results.*
- PN-G-04035:2002 + Az1:2005 *Air purity protection in underground mining plants. Measurement of dust concentration in the air and determination of the content of free crystalline silica in the dust.*

For collecting samples of harmful substances (dust), the individual dosimetry method was employed using individual pumps, which enable the collection of air samples in the employee's breathing zone continuously for a period of at least 75% of the duration of the working shift. The tests of the respirable fraction and inhaled dust were based on the following standards:

- PN-91/Z-04030.06 *Determination of respirable dust at workplaces using the filtration-weighing method.*
- PN-91/Z-04030.05 *Determination of total dust at workstations using the filtration-weighing method.*

The basis for determining the concentration of crystalline silica was the method of infrared spectrometry (Maciejewska, 2012).

Before starting the measurements, an on-site inspection was made and information was collected on the following:

- location and naming of the workplace,
- type and course of technological processes,

- types of machines, devices, and activities performed,
- harmful factors specific to given technological processes,
- time of exposure to factors harmful to health (i.e., exposure time).

For the measuring equipment, individual aspirators type 224-44MTX by SKC were used to take air samples at workplaces, which are checked each time before and after the measurement with a rotameter type ROS-06 with the serial number 079901, containing a calibration certificate issued by the Regional Office of Measures (OUM) in Poznań accredited in PCA (No. AP 084). The filters used for measurements were dried to a constant mass in a desiccator and then weighed on a RADWAG AS60/220.R2 balance, serial number 508222, with a verification certificate issued by "TOPS" S.C. Mass Measurement Laboratory accredited by PCA (No. AP 093).

Each filter was assigned appropriate frames (inhalable fraction) and cyclones (respirable fraction). To determine the concentration of chemical substances at workplaces, tests and measurements were performed based on: PN-Z-04008-7:2002 and PN-Z-04008-7:2002/Az1 December 2004 *Principles of air sampling in work environment and interpretation of results*.

Based on the determined concentration values in the samples of dust (and/or chemicals), the average weight concentration was determined – formulas (1) and (2) – and the EC exposure indicators were calculated for the entire work shift – formula (3). For samples taken by individual dosimetry on the basis of formula (1), we find:

$$C_w = \frac{C_1 \cdot t_1 + C_2 \cdot t_2 + C_3 \cdot t_3 + \dots + C_n \cdot t_n}{t_1 + t_2 + t_3 + \dots + t_n} \quad (1)$$

where $C_1, C_2, \dots, C_n$ represent the concentrations obtained as a result of the determination of individual samples [mg/m^3], t_i is the time of taking individual samples [min], and n is the number of samples.

For samples taken by the stationary method, based on formulas (2) and (3), it is determined that:

$$\bar{X}_{gw} = \frac{\bar{X}_{g1} \cdot t_1 + \bar{X}_{g2} \cdot t_2 + \bar{X}_{g3} \cdot t_3 + \dots + \bar{X}_{gk} \cdot t_k}{t_1 + t_2 + t_3 + \dots + t_k} \quad (2)$$

where $X_{g1}, X_{g2}, \dots, X_{gk}$ denote the concentrations obtained as a result of the determination of individual samples [mg/m^3], $t_1, t_2, t_3, \dots, t_k$ is the duration of individual measuring periods in minutes, and k is the number of measuring periods. In addition:

$$W_E = C_w \cdot \frac{T_e}{T_o} \quad \text{or} \quad W_E = \bar{X}_{gw} \cdot \frac{T_e}{T_o} \quad (3)$$

where C_w, X_{gw} signifies the weighted average concentration of a specific dust/chemical type, expressed in [mg/m^3], T_e is the exposure time per shift, expressed in minutes, T_o is the reference time for an 8-hour run time, i.e., 480 minutes, and W_E is the exposure index.

The working conditions are considered safe if the calculated exposure index does not exceed the value of the maximum permissible concentration (NDS) for a given substance, and the exposure index (WN) is less than or equal to 1 in the following formula:

$$W_N = \frac{W_E}{\text{NDS}} \leq 1 \quad (4)$$

where W_N represents the exposure factor, W_E is the exposure index for total or respirable dust or chemical, expressed in [mg/m^3], and NDS is the maximum permissible concentration for total or respirable dust or a chemical substance, expressed in [mg/m^3].

For the collection of samples of harmful substances (chemical agents), the individual dosimetry method was used, using individual pumps that allow for the taking of air samples in the breathing zone of the employee, continuously for a period of at least 75% of the duration of the working shift. For the measuring equipment, individual aspirators type 224-44MTX by SKC were used to take air samples for testing the concentration of chemical substances at workplaces, which are checked each time before and after the measurement with a rotameter type ROS-06 with the serial number 079901, having a calibration certificate issued by OUM in Poznań accredited in PCA (No. AP 084). The filters used for measurements were dried to a constant mass in a desiccator and then weighed on a RADWAG AS60/220.R2 balance, serial number 508222, with a calibration and calibration certificate issued by "TOPS" S.C. Mass Measuring Laboratory accredited by PCA (No. AP 093).

Chemical analysis was performed with the following equipment:

- crystalline silica: Perkin Elmer FT-IR Spectrum TWO spectrophotometer, serial number 97389 – polystyrene foil calibration certificate issued by the Central Office of Measures – via the method of infrared absorption spectrophotometry.

Prophylactic diagnostic tests of employees of selected preparation plants were performed based on a medical interview with the patient, physical examinations, and spirometry.

Results and discussion

One of the basic organizational structures of each deep coal mine is the preparation work plants, whose main task is to make the coal seam or deposit available by dividing it along and across selected fields by means of preparatory excavations, which include sidewalks, ramps, tops, slopes, longwall cuts, etc. Preparatory workings, also known as corridor workings, can be performed on one mining level at a slight slope, and then they most often serve as longwall workings for the designed service walls. They can also be bored as sloping headings connecting two or more points at different levels of the mine. Preparation plants also drill other underground facilities such as chambers, depots, warehouses, settling tanks, etc. Depending on the system of works used, preparatory workings are drilled in coal, stone, or a combination of these geological structures using mining machines or explosives. Due to the limited spatial dimensions of the preparatory workings (height 3.0–5.5 m, width 3.5–8.0 m, long runs reaching even several kilometers) and the limited ventilation possibilities, the technological processes used in their implementation cause immense dustiness in the air. In the latter, apart from ground particles of coal and stone, there may be other minerals including free crystalline silica (Figure 1).

As part of the research, air dustiness was measured at three preparation plants: GRP-1 – carrying out works in a drilled mine face with the use of an AM-50 roadheader, GRP-2 – drilling a rock surface with explosives, and GRP-3 – leading coal with the

AM-75 combine. Suction duct ventilation was used in all the excavated workings.

The results of dust measurements at selected positions of the preparatory works departments of mine X are presented in Table 1; the chemical substances are given in Table 2. The following numbers were assigned to individual workstations: roadheader operator – 1, roadheader operator's assistant – 2, miner-builder – 3, miner in transport – 4, conveyor service – 5, face miner – 6, blast miner – 7, and drill – 8.

The circumstances of the sampling during the 450-minute exposure period included activities performed by employees of the preparation plant, such as:

- ingress and exit through the shaft to the mine, riding the railway to the area of the longwall, and access and return from the workplace,
- preparatory works,
- operation of roadheader, conveyors, and face devices,
- mining with a roadheader and mining with explosives,
- development of the pavement housing elements and the liner,
- drilling blast holes and control holes,
- transport of materials to the longwall, lengthening of the lute, and reconstruction of mine face devices,
- technological breaks.

The conducted research shows that all workplaces in the examined preparation plants are endangered by excessive exposure to dust and harmful substances.



Figure 1. Dustiness during mine face works with the use of the AM-50 roadheader and explosives

Table 1. Results of the measurements of air dustiness with hard coal dust at individual positions of preparation plants using the dosimetric method

Ward	Position	Dust concentration range in the fraction [mg/m ³]		Indicator W_E [mg/m ³]		NDS		Indicator W_N (times of NDS)	
		Inhaled	Respirable	Inhaled	Respirable	Inhaled	Respirable	Inhaled	Resp.
GRP-1	1	0.71–48.68	0.35–15.12	46.33	14.63	10	2	4.6	7.3
	2	0.68–46.13	0.30–14.65	44.18	14.14	10	2	4.4	7.1
	3	0.44–39.48	0.15–11.31	33.52	10.45	10	2	3.4	5.2
	4	0.25–24.14	0.07–8.30	42.30	12.80	10	2	4.2	6.4
	5	0.32–34.20	0.13–10.38	30.17	8.46	10	2	3.0	4.2
GRP-2	1	0.51–35.10	0.26–9.11	33.82	10.20	10	2	3.4	5.1
	2	0.48–33.22	0.20–9.64	31.36	9.34	10	2	3.1	4.7
	3	0.28–26.46	0.11–7.30	24.29	7.28	10	2	2.4	3.6
	4	0.09–21.13	0.07–6.35	19.21	6.13	10	2	1.9	3.1
	5	0.23–31.77	0.15–8.38	31.20	8.96	10	2	3.1	4.5
	6	0.12–26.30	0.04–6.33	24.78	7.47	10	2	2.5	3.7
GRP-3	3	0.10–7.91	0.02–1.46	7.36	1.36	10	2	0.7	0.7
	4	0.08–7.83	0.01–1.23	7.23	1.12	10	2	0.7	0.6
	5	0.24–12.6	0.04–2.02	11.3	1.98	10	2	1.1	1.0
	6	0.09–7.42	0.01–1.11	6.84	0.93	10	2	0.7	0.5
	7	0.31–8.96	0.03–1.43	8.20	1.17	10	2	0.8	0.6
	8	0.26–7.38	0.02–1.26	6.65	1.10	10	2	0.7	0.6

Table 2. Measurement results of the chemical substance of crystalline silica at individual stations of the preparation plants using the dosimetric method

Ward	Position	Concentration range of crystalline silica in the respirable fraction [mg/m ³]	Indicator W_E [mg/m ³]	NDS of respirable fraction	Indicator W_N (times of NDS)
GRP-1	1	0.037–0.335	0.312	0.1	3.1
	2	0.034–0.316	0.296	0.1	3.0
	3	0.023–0.285	0.262	0.1	2.6
	4	0.040–0.348	0.319	0.1	3.2
	5	0.026–0.289	0.243	0.1	2.4
GRP-2	1	0.046–0.621	0.600	0.1	6.0
	2	0.038–0.610	0.592	0.1	5.9
	3	0.026–0.555	0.514	0.1	5.1
	4	0.009–0.214	0.196	0.1	2.0
	5	0.028–0.582	0.563	0.1	5.6
	6	0.025–0.430	0.403	0.1	4.0
GRP-3	3	0.058–0.918	0.890	0.1	8.9
	4	0.031–0.466	0.421	0.1	4.2
	5	0.076–1.215	1.200	0.1	12.0
	6	0.047–0.860	0.842	0.1	8.4
	7	0.060–1.110	0.983	0.1	9.8
	8	0.067–1.126	1.089	0.1	10.9

The highest concentrations of dust are found at the roadheader operator and roadheader operator's assistant's stands in longwall excavated with a roadheader, and at the drill and blaster's stands in coal faces prepared with the use of explosives. The presence of crystalline silica in the air inhaled by miners, even in the coal face, undoubtedly has a decisive impact

on the state of danger for the working mining crews, where its content should theoretically be negligible.

It turns out that the fresh air supplied to the coal face already contains significant amounts of silica, which make it exceed the current normative values for this chemical substance at the workplace. Therefore, the frequency of environmental measurements

Table 3. Frequency of measurements depending on the concentrations of harmful factors found

Workplace number			Indicator W_N (times of NDS)	Research frequency
GRP-1	GRP-2	GRP-3		
Name of the harmful factor – coal (hard coal and lignite)				
			NDS < 0.1	*
			$0.1 < W_N < 0.5$ NDS	At least every two years
1,2,3,4,5	1,2,3,4,5,6	3,4,5,3,7,8	$W_N > 0.5$ NDS	At least once a year
Name of the harmful substance – crystalline silica (quartz and cristobalite)				
			$0.1 < W_N < 0.5$ NDS	At least once every six months (carcinogenic or mutagenic agents are present)
1,2,3,4,5	1,2,3,4,5,6	3,4,5,3,7,8	$W_N > 0.5$ NDS	At least once every three months (carcinogenic or mutagenic agents are present)

* – according to § 7. Regulation of the Minister of Health of 02.02.2011 on tests and measurements of agents harmful to health in the work environment (Journal of Laws No. 33 of 2011), as amended.

at the mine is increasing (Table 3) and, consequently, the employer should take additional preventive measures to improve working conditions and monitor the health of people exposed to carcinogens.

To supplement the collected results of measurement tests, anonymous diagnostic tests of the respiratory system were also performed among the 87 employees of the preparation plants (GRP-1, GRP-2, and GRP-3) of mine X. Their aim was to assess the frequency of respiratory disorders among the examined miners. The scope of diagnostic tests included:

a) medical interview with the patient – the purpose of which was to become acquainted with: the employee's identification data; his

individual characteristics such as age, height, and body weight; health ailments; illnesses; family health burdens, lifestyle, addictions, and working conditions. In this study, the CAT – COPD Assessment Test (Farnik et al., 2019) was used to assess the patient's current ailments, which identified the patient's symptoms such as cough, sputum retention, tightness in the chest, daily activity at home and outside, dyspnea, anxiety and uncertainty, sleep disturbances, and energy to act (Table 4).

b) physical examination – the purpose of which was to conduct a general assessment of the health and appearance of the examined employee using the

Table 4. Results of the CAT test of the employees of the preparation plant of mine X

Occurring symptoms	Age of respondents							
	≤ 20	21–25	26–30	31–35	36–40	41–45	46–50	> 50
	Total number of respondents (responders (smokers))							
	2 (1)	7 (4)	10 (4)	14 (10)	23 (18)	16 (11)	9 (4)	6 (3)
Number of respondents (average CAT points)								
Cough	–	2 (3.0)	2 (3.5)	–	11 (3.4)	9 (3.7)	6 (3.5)	5 (4.2)
Residual sputum	2 (3.0)	2 (3.0)	10 (3.0)	14 (3.3)	23 (3.5)	16 (3.5)	9 (4.0)	6 (4.5)
Tightness in chest	–	–	–	–	2 (3.0)	3 (2.7)	4 (3.5)	2 (3.5)
Shortness of breath	–	–	–	–	2 (3.5)	3 (3.3)	4 (3.8)	2 (3.5)
Tiredness	–	–	2 (3.5)	–	5 (3.0)	8 (3.4)	4 (3.5)	5 (4.0)
Anxiety and insecurity	–	–	–	–	–	2 (3.0)	2 (3.0)	2 (3.0)
Sleep disturbance	–	–	–	–	–	2 (3.5)	3 (3.7)	2 (3.5)
Lack of energy	–	–	1 (3.0)	–	5 (3.6)	3 (3.6)	6 (3.3)	2 (3.5)
CAT result	< 10	< 10	13	< 10	20	26.7	27.3	29.7

Interpretation of CAT results

1. 5 points – Upper limit of normal for healthy, non-smokers.
2. < 10 points – Little impact of the disease on life. Most good days. Fatigue symptoms.
3. 10–20 points – Average impact of the disease on life. Appearing shortness of breath, cough, 1–2 exacerbations a year.
4. 21–30 points – Big impact on life. If you are ill, you are unable to do most activities.
5. > 30 points – Very big impact on life. Difficult to perform basic activities.

senses of sight, hearing, and touch. This consisted of the following:

- viewing: including the patient's skin and its discoloration, the shape and appearance of the chest in terms of its structure, and the shape of the fingers of the hands;
 - assessment of breathing: the proportion of inhalations and exhalations, breathing paths, chest mobility, number of breaths per minute, and respiratory disorders;
 - palpation: assessing symmetry of chest respiratory movements, determining local rib pain, and assessing vocal tremor and the presence of air in the subcutaneous tissue;
 - chest percussion: determine the size and mobility of the lungs, recognize fluid or air in the pleural cavity, or airlessness of the lung parenchyma;
 - auscultation: enabling the detection of respiratory anomalies in the form of bronchial and pulmonary respiratory sounds, crackles, and wheezes (Table 5).
- c) spirometric tests, the purpose of which was to determine the capacity and volume of the lungs of the studied workers and the airflow that occurs during various phases of the respiratory cycle. The tests were performed with the Lungtest mobile spirometer by MES, in accordance with the criteria of correctness and repeatability of basic spirometry tests according to the recommendations of the ATS – American Thoracic Society (Boros,

Mejza & Gomółka, 2019). For the correctness of the tests, the apparatus was calibrated before each measurement. The employee's personal characteristics – such as age, sex, height, and body weight – were entered into the memory of the measuring device (spirometer). The examination was performed in a sitting position with the clip on the nose. The attempt to draw air into the lungs and blow air into the spirometer was repeated three times and was considered reliable if the obtained results were similar. Airway obstruction was determined in accordance with the recommendations of the GOLD report for COPD (Graham et al., 2019) based on the finding of airflow limitation during exhalation based on the obtained FEV1/FVC and FEV1 values (Table 6).

The diagnostic tests were performed based on the interviews, and the CAT test showed that over 12.6% of the surveyed miners of the preparation plants of mine X experience disturbing respiratory ailments, which clearly intensify after the age of 40 and, on average, after 17 years of continuous exposure to dust. Increased symptoms were diagnosed in road-header operators and workers transporting broken coal from longwall, even though 56% of workers with symptoms of respiratory system disorders have never smoked cigarettes or are not exposed to industrial dust outside the mine. Minor ailments manifested by residual sputum and cough are experienced by many respondents who everyday attempt

Table 5. Results of the physical examination of the employees of the preparation plants of mine X

Identified symptoms	Age and number of respondents							
	≤ 20	21–25	26–30	31–35	36–40	41–45	46–50	> 50
	2	7	10	14	23	16	9	6
	Number tested with symptoms							
Skin changes	–	–	–	–	–	–	2	1
Chest deformity	–	–	–	–	–	1	1	1
Clubbed fingers	–	–	–	–	1	–	1	2
Shortness of breath, apnea	–	–	–	–	2	3	5	3
Prolonged exhalation	–	–	2	–	–	–	1	1
One-sided weakening of chest movements	–	–	–	–	1	2	3	2
Decrease in the number of breaths	–	–	–	–	–	2	4	2
Breathing disorders	–	–	–	1	2	2	5	3
Lowering the lungs	–	–	–	–	–	2	2	1
A dull percussion noise	–	–	–	–	–	1	2	1
A tympanic percussion noise	–	–	–	–	–	–	2	1
Voice tremor	–	–	–	–	1	1	2	2
Bronchial or pulmonary respiratory sounds	–	2	1	3	11	6	5	4
Wheezing	–	–	–	1	3	2	3	2
Crackles	1	1	4	7	10	3	2	2
Pleural friction rub	–	–	–	–	–	–	1	2

Table 6. Degree of lung function impairment in the spirometric test of employees of preparation plants of mine X

Degree of obstruction	Eligibility criteria according to FEV1	Age and number of respondents							
		≤ 20	21–25	26–30	31–35	36–40	41–45	46–50	> 50
		2	7	10	14	23	16	9	6
Number tested with symptoms									
Slight	> 80%	–	1	1	1	1	1	1	1
Moderate	50–80%	–	–	–	–	1	2	2	1
Severe	30–50%	–	–	–	–	–	–	1	2
Very severe	< 30%	–	–	–	–	–	–	–	–

to remove impurities entering the respiratory system during work. The obtained results of the interview are also confirmed by physical examinations, especially auscultatory ones, which in almost half of the respondents (48.3%) show crackles, wheezes, whirring indications of narrowing of the airways inside or behind the chest, and the presence of secretions in the respiratory tract.

Interestingly, these states are observed not only in the elderly, but also in young workers between 20–30 years of age employed (especially in longwalls). Unfortunately, among the surveyed employees, there may be cases of atelectasis, emphysema, and reduced aeration of lung tissue, as evidenced by dull and tympanic percussion noise (7% of respondents). The research also shows the possibility of neoplastic changes in 4.6% of the respondents, manifested by pleural friction and clubbed fingers, which may indicate neoplastic fibrous lesions of the lung tissue. This observation was also confirmed by spirometric tests, which in 3.5% of respondents showed a severe degree of respiratory obstruction below 35%. In general, the features of respiratory obstruction were diagnosed in 16 people, i.e., 18.4% of the respondents. This is a significant result, especially when only two surveyed employees of the preparation plants of mine X were under the supervision of a pulmonologist; the rest were unaware of their ailments. Their preventive examinations in the diagnosis of respiratory diseases were mostly limited to a chest X-ray performed every few years. All persons diagnosed with the features of respiratory obstruction as part of the research conducted by the Department of Safety Engineering in mine X were sent for further diagnostic tests.

The conducted research is consistent with the results obtained by other researchers from Poland (Boros et al., 2022) and from abroad (Gandhi et al., 2021), who also indicated the need to extend diagnostic tests to people exposed to the harmful effects of dust (Tinkelman et al., 2007).

Conclusions

The research concept proposed by the authors, which combined the assessment of the actual working conditions in the zone of harmful dust impact with simultaneous diagnostic tests of miners exposed to them, brought measurable benefits that include the recognition of the scale of the threat. This manifested not only in the scope of exceeding the normative values at individual workplaces, but also in recognizing various diseases among miners. The obtained results indicate the need to continue research among employees of other departments of mine X, where the risk of harmful dust is also high, and to continue searching for scientific and technical solutions limiting the scale of the threat.

As shown by the environmental and medical research carried out among the employees of the preparatory departments of mine X, the current personal protective equipment – i.e., disposable filtering half-masks and collective protection measures, dust removal devices, sprinkler systems, and water curtains used in mining – are not able to completely eliminate the disease risk among employees, despite the advancement of knowledge and new technical solutions. This problem is particularly visible in the case of dust that contains free crystalline silica; therefore, most European countries have limited the limit values for respirable silica to values not exceeding 0.1 mg/m³. In Poland, these changes were made as a result of the implementation into Polish law of Directive (EU) 2017/2398 of the European Parliament and of the Council of 12 December 2017 amending Directive 2004/37/EC on the protection of workers against the risks related to exposure to carcinogens or mutagens at work (EUR-Lex, 2017) and extending the provisions of the Regulation of the Minister of Health on chemical substances, their mixtures, agents, or technological processes with carcinogenic or mutagenic effects in the work environment to include “work related to exposure

to crystalline silica – a respirable fraction generated during work” (ISAP, 2020). The introduced provision imposes on employers and doctors, who provide preventive health care for employees working in conditions of exposure to harmful dust, additional obligations consisting not only in increasing environmental measurements for air dustiness but also extending medical prophylaxis.

The conducted research and the obtained results also indicate the need to extend the medical prophylaxis among mine workers with additional tests, including spirometry, full-size chest image, capillary blood gas tests, peripheral blood counts or low-dose, and high-resolution computed tomography allowing for lung cancer screening. Such a conclusion is supported not only by the growing statistics of the incidence of pneumoconiosis in Poland, but also by new cases of pulmonary lesions identified during the research performed on the employees of the preparation departments of mine X who, according to the conducted medical interviews, are often unaware of their own ailments and underestimated disease symptoms.

An important goal of people responsible for the safety of employees in mines should also be to increase the work safety culture and the gradual replacement of the disposable FS-0/30V and FS-58V A filtering half masks, which become wet quickly in underground conditions, with reusable silicone half-masks containing filters such as SECURA DUST. Only a systematic approach to the issue of hazardous dust harmful to health, not only in mining, can limit the drama of many people exposed to numerous years of excessive exposure to industrial dust and reduce the upward trend in the incidence of occupational pneumoconiosis.

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Deformations of a dog heading located in an area of intensive mining operation – case study

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Abstract

The article presents results on the influence range of mining exploitation in a rock mass at the site of dog headings located in an area of intensive mining exploitation. The research is based on geodetic measurements of the subsidence of measurement line points located above the panel of a mined-out longwall. Studies were applied to assess the range of mining influence in a rock mass, which is important for the protection of dog headings against mining damage. If a range of mining influence comprises any protected workings, then the deformations caused by mining operations may result in the loss of their functionality and even in dangerous damage to them. The values of the parameters of the influence theory determined by geodetic measurements of subsidence can be used to determine the permissible length of longwall panels, ensuring the maintenance of the functionality of the protected dog headings and to optimize stress concentration zones in terms of the risk of rock mass tremors.

Introduction

The impact of underground mining of a deposit on objects located in the rock mass has always been the subject of research and experimentation. Yet, despite significant achievements of science in this field, the problem still requires comprehensive research, mainly due to the increased depth of mining exploitation and its intensity. In such conditions, an important mining and technological problem is to maintain the functionality of dog headings, which are indispensable to carry out mining operations and which are placed in the mining fields. Pillars left behind for the protection of dog headings cause many negative effects, such as high concentration of stresses in the rock mass, resulting in the occurrence

of tremors, reduction of panel length, difficulties in rational deposit management and deposit loss (Zhu, Jiang & Liu, 2015; Zhu et al., 2022).

Frequently, despite leaving the pillars behind, damage to dog headings is reported, which results in loss of their functionality and rising costs. In the case of the undermining of dog headings, geodetic measurements of deformations occurring in them, even to a small extent, are extremely informative and valuable for scientific purposes. The results of such measurements may also serve as a basis for the application and verification of the protection principles of such workings.

The article presents the results of research on rock mass deformations in Cross-cut I and in Main Entry (i.e., in the excavations located above the

panel length of the mined-out longwall C-1 in the seam 505wd) for the assessment of the influence range of this mining operation, which determines the required size of a protective pillar.

Mining conditions in the investigated intensive mining operation area in terms of protection of dog headings

The investigated case of dog heading protection involves a mining area where intensive mining has been conducted for many years. The scope of this mining exploitation in a graphical form with marked longwall contours is presented in Figure 1.

In such mining conditions, the protection of main dog headings is of particular importance, which should ensure their stability and functionality and hence the possibility of effective and planned mining of a coal deposit. The stability of dog headings is understood as their ability to remain fully operational for a specified period of time (i.e., to be technologically usable) (Białek & Mielimąka, 1999).

As to the influence of mining exploitation on dog headings, of prime importance for ensuring their safe exploitation and required functionality is the size and distribution of the deformations, characterized by the so-called deformation indicators. The value of rock mass deformation indices caused by the impact of mining exploitation can be used to

assess the effects of deformations that arise in dog headings.

In view of our experience, we can state that the size and intensity of the impact of mining exploitation have a fundamental influence on the possibility to maintain safe and economically justified functionality of a working mine.

The impact of mining exploitation on dog headings depends on a number of natural and mining factors, and above all, on the time and spatial location of such workings in relation to the mining plots (mining longwalls). In terms of time, two cases can be distinguished (Białek, 2003):

- mining of a dog heading in the rock mass disturbed by previous mining operations,
- maintenance of a dog heading within the range of a mining operation.

In terms of the spatial location of a dog heading within the impact range of mining exploitation, the following can be distinguished (Białek, 2003):

- undermining a dog heading,
- overmining a dog heading,
- a mining operation carried out in the area of a dog heading.

Description of the measurement line

The aim of the presented studies of rock mass deformations at the place of dog headings located in

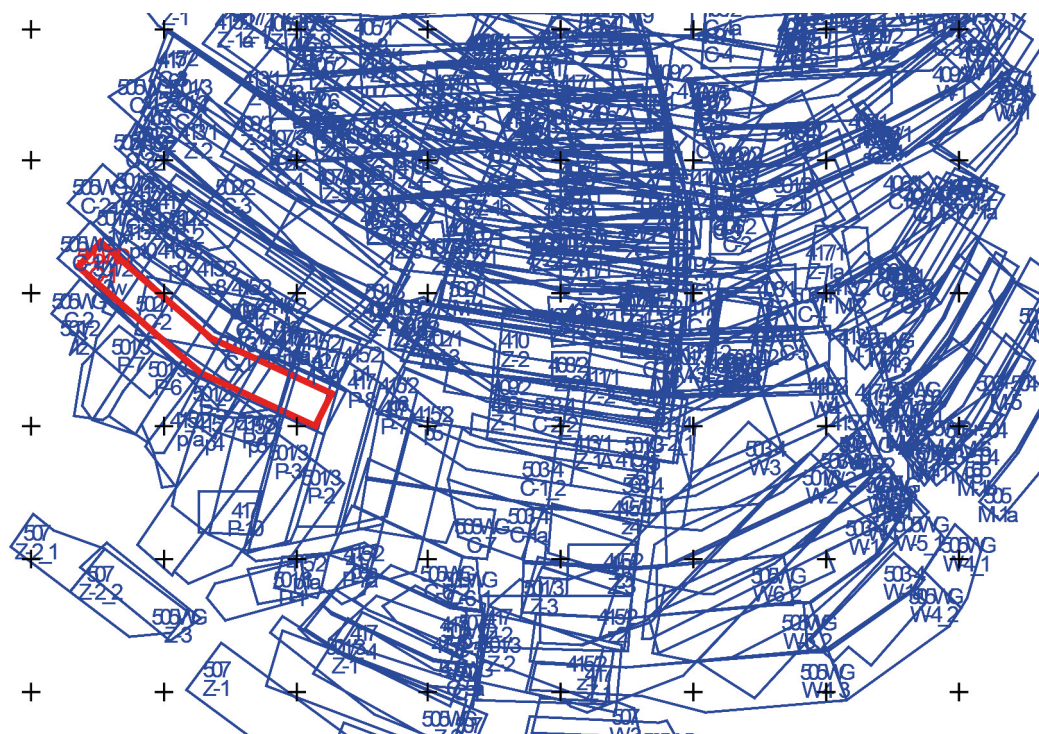


Figure 1. Contours of longwalls in the discussed area (longwall C-1 in the seam 505wg is marked in red)

an area of intensive mining exploitation was to verify the data on the range of mining influence in the rock mass in this area. The range of mining exploitation impact determined by the results of geodetic measurements of deformations is the basis for determining the permissible planned panel length, ensuring the maintenance of the functionality of the protected dog headings and the optimization of stress concentration zones in terms of the risk of rock mass tremors (Mielimaka & Kleta, 2020; Mielimaka et al., 2021).

The study of rock mass deformations was based on the results of displacement measurements carried out in Cross-cut I and in Main Entry located above the panel length of the mined longwall C-1 in seam 505wd (Figure 2). Longwall C-1 is located in the bottom layer of seam 505. The total thickness of seam 505 in this area ranges from about 6.50 m to 8.50 m. Seam 505 was mined in layers, and the upper layer was mined in the years 2010–2017. The exploitation of the bottom layer was carried out, leaving behind a rashing in the roof with a thickness of about 1.0 m, which made it possible to maintain the roof which had a high tendency to subside. This allowed for safe exploitation under the goaf of the first layer of seam 505.

The roof of seam 505 consists of clay shale and sand shale layers. At the initial part of the panel length, the roof of the seam is made of clay shale, above which there is sand shale and a layer of medium and fine sandstone, while further along the panel length of longwall C-1, the sandstone turns into sand shale. At the further and final part of the panel length in the roof of the seam, there is a layer of clay shale covered with sand shale. In the floor of seam 505 there is sand shale and, locally, clay shale.

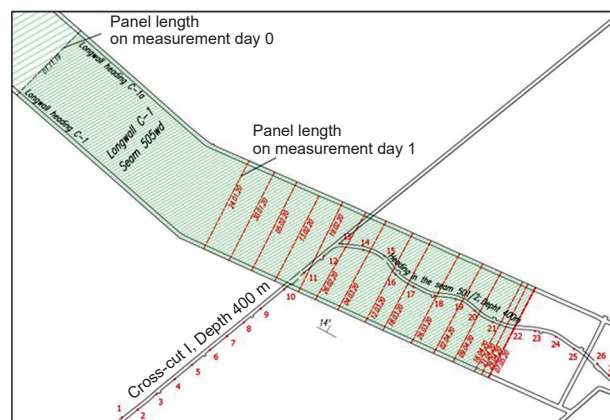


Figure 2. Location of the measurement line (points 1–28) in relation to the plot of longwall C-1 in seam 505wd

The deformations of the cross-cut and heading are characterized by measured deformations in the form of subsidence of the measurement points of the observation line made of 28 points located equally at intervals of approx. 30 m apart. In the period from 07/11/2019 to 27/05/2020, 18 height measurement cycles were performed on the measurement line, which indicated subsidence at the measurement points caused by the realization of subsequent stages of the exploitation of longwall C-1 in seam 505wd, until its completion. The location of the measurement line in relation to the area of longwall C-1 in seam 505wd is shown in Figure 2, and the subsidence of the observation line points in individual measurement cycles in relation to the initial measurement is shown in Figure 3.

As demonstrated in Figure 3, the exploitation of longwall C-1 in seam 505wd resulted in the subsidence of measurement line points in subsequent measurement cycles, and the maximum subsidence (0.816 m) was recorded in the last cycle (18th) at point 15.

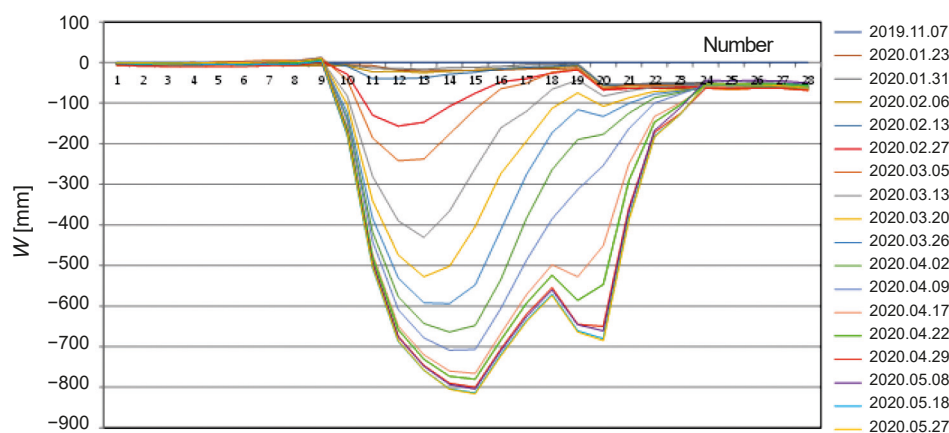


Figure 3. Measured subsidence of the measurement line points in subsequent observation cycles caused by progressive exploitation of longwall C-1 in seam 505wd

Theoretical basis of the applied theory of influence in the conducted research

Research and forecasts involving the impact of mining exploitation on surface ground and rock masses have been performed in Poland mainly by numerical methods using the formulas of S. Knothe's theory (Knothe, 1984), or in line with formulas developed by J. Białek (Białek, 2003), which are modifications of this theory that enable the forecast to include the effect of a mining periphery and the so-called far influences.

In the classic form of S. Knothe's theory, commonly used to describe a deformation, the subsidence caused by the exploitation of a horizontally placed mining plot is described by the following relationship (Knothe, 1984):

$$w(x, y, ag, r, S(t)) = \frac{-ag}{r^2} \iint_{S(t)} \exp \left\{ -\pi \left[\frac{(x-\xi)^2 + (y-\eta)^2}{r^2} \right] \right\} dS \quad (1)$$

where:

r – radius of influence scattering determined by measurements or calculated from the formula $r = h(\xi, \eta) / \operatorname{tg} \beta$,

x, y – coordinates of the calculation point,

$S(t)$ – area of the exploited bed, which is generally a function of time t ,

ξ, η – coordinates of the surface element dS ,

$ag = w_{\max}$ – maximum subsidence of the so-called full subsidence trough.

In the formula of J. Białek implemented in the calculation programs, the theoretical subsidence is determined by the following formula (Białek, 2003):

$$W_k = (1 - a_w)w(r_1) + a_w w(r_2) + -A_1 \left(2 + \frac{A_3}{2} \right) \frac{w(r_1)[r_1 \gamma(r_1)]^2}{A_3 [0.5w(r_1) + 0.5w(r_2)]^2 + [r_1 \gamma(r_1)]^2} \quad (2)$$

where:

$A_1 = A_{\text{obr}}$ – parameter capturing the asymmetry of the subsidence trough profile, $A_1 \approx d/r$ (d – periphery),

$w(r_1), w(r_2)$ – subsidence calculated by Knothe's formula (eq. (1)) using radii r_1, r_2 ;

$A_3 = 6.667$,

$\gamma(r_1)$ – octahedral deformation calculated for $A_2 = 0.25$ with a simplified formula, in which horizontal movements are ignored. To describe its components, Knothe's formula was used, in the following form:

$$\gamma^2 \approx \gamma_{oct}^2 \approx \frac{4}{3} \varepsilon_z^2 + T_x^2 + T_y^2 \approx$$

$$\approx \left[A_2 \cdot r \cdot \left(\frac{\partial^2 w}{\partial x^2} + \frac{\partial^2 w}{\partial y^2} \right) \right]^2 + \left(\frac{\partial w}{\partial x} \right)^2 + \left(\frac{\partial w}{\partial y} \right)^2$$

$$a_w = 0.4 - 1.25A_1, \quad r_1 = \frac{h}{\operatorname{tg} \beta} F(A_1), \quad r_2 = 2r_1$$

A_1	0	0.050	0.100	0.150	0.200	0.250	0.300
$F(A_1)$	0.800	0.844	0.916	1.003	1.099	1.200	1.303

The first two components of Formula (2) are a superposition of two subsidence troughs with different radii of influence range, which allows for a description of the so-called far influence. The third component of Formula (2) allows the calculations to take into account the mining periphery, which means that the subsidence over the exploitation edge is much lower than half of the maximum subsidence, and the trough profile is asymmetric with respect to this edge.

The most important feature of the programs EDBJ and EDN-OPN used in the research is the fact that they take into account the development of mining exploitation over time (Białek, 2003). An important consequence of the used description of the exploitation over time is the possibility to obtain forecasts of deformation rates treated as an increment of their values from one specific date to another. Moreover, it is possible to obtain a forecast of the extreme in time values of the deformation indices.

Determination of the values of parameters from the measured subsidence of measuring line points

To determine the parameters of the influence theory of mining exploitation based on geodetic measurements in Cross-cut I and in Main Entry, the TGB.EXE program was used, which determines the parameters $a, \operatorname{tg} \beta, A_{\text{obr}}$ (Formulas (1), (2)) and adopts the residual variance minimum as the criterion for determining the parameters, defined by the formula (Mielimąka, 2009; Białek et al., 2020):

$$B_1(a, \operatorname{tg} \beta, A_{\text{obr}}) = \sum_{i=1}^n [a W_{k_i}(\operatorname{tg} \beta, A_{\text{obr}}) - W_{p_i}]^2 \quad (3)$$

where:

n – number of measurement points,

a – exploitation coefficient,

$\operatorname{tg} \beta, A_{\text{obr}}$ – parameters present in formulas (1) and (2),

$aW_{k_i}(\text{tg}\beta, A_{\text{obr}})$ – theoretical value of the subsidence of the i -th measuring point,
 W_{p_i} – measured subsidence of the i -th measuring point.

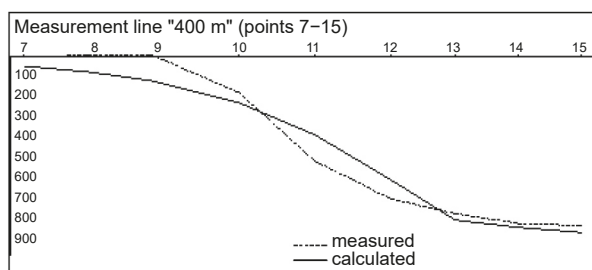


Figure 4. Waveforms of final subsidence of the measured points 7–15 of the “400 m” measuring line and theoretical subsidence adjusted by them

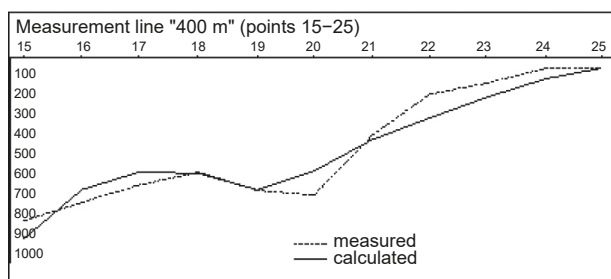


Figure 5. Waveforms of final subsidence of the measured points 15–25 of the “400 m” measuring line and theoretical subsidence adjusted by them

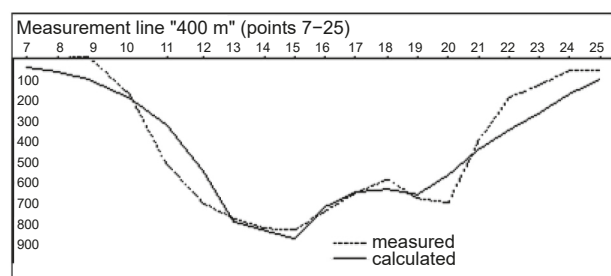


Figure 6. Waveforms of final subsidence of the measured points 7–25 of the “400m” measuring line and theoretical subsidence adjusted by them

Table 1 summarizes the parameters of Knothe’s theory of influence and formulas developed by J. Białek obtained with the program TGB.EXE.

Table 1. Summary of numerically determined parameters of the theory of influence based on subsidence measurements in Cross-cut I and Main Entry

Measurement points	Subsidence coefficient a	Parameter $\text{tg}\beta$	Periphery parameter A_0	Standard deviation	Correlation factor
7–15	0.692 ± 0.598	1.224 ± 0.086	0.000 ± 0.194	77.1 mm	0.9753
15–25	0.791 ± 0.282	2.096 ± 0.239	0.129 ± 0.052	69.4 mm	0.9684
7–25	0.813 ± 0.375	1.368 ± 0.098	0.084 ± 0.068	90.7 mm	0.9556

Average errors of these parameters were determined with the program BLAD_TGB.EXE.

Relatively large errors in the determined values of the parameters of the influence theory (Table 1) resulted from a relatively low accuracy of geodetic measurements, stabilization of points in the lining of the workings, and the impact of the goaf from the previously exploited upper layer of seam 505wg.

The determined values of parameter $\text{tg}\beta$ are lower than the value of this parameter accepted in the influence forecasts for surface ground, determined from the subsidence measurements on the observation lines located on the surface ground in this area.

Taking into account the values of the determined parameters of the influence theory (Table 1) and the values of their mean errors, as well as the values of the quantities characterizing the matching accuracy of theoretical subsidence with the measured ones, it can be assumed that the best approach is to describe the deformations that occurred in dog headings using the values of the parameters of the influence theory equal to $a = 0.813$, $\text{tg}\beta = 1.368$, $A_0 = 0.084$.

Determination of deformation indicators at measurement line points in Cross-cut I and Main Entry

The values of deformations at the measurement line points were calculated numerically by using the values of parameters of the theory of influence accepted as optimal ($a = 0.813$, $\text{tg}\beta = 1.368$, $A_0 = 0.084$).

Figures 7–10 show the distribution of the most important deformation indices calculated numerically at the measurement line points in Cross-cut I and Main Entry.

The performed numerical calculations of selected deformation indices at the measurement line points in Cross-cut I and Main Entry (Figures 7–10) indicate that the workings in question could have been subject to the maximum influences amounting to resultant horizontal displacements – 525 mm and main horizontal deformations – -11.05 mm/m. The deformations to which Cross-cut I and Main Entry

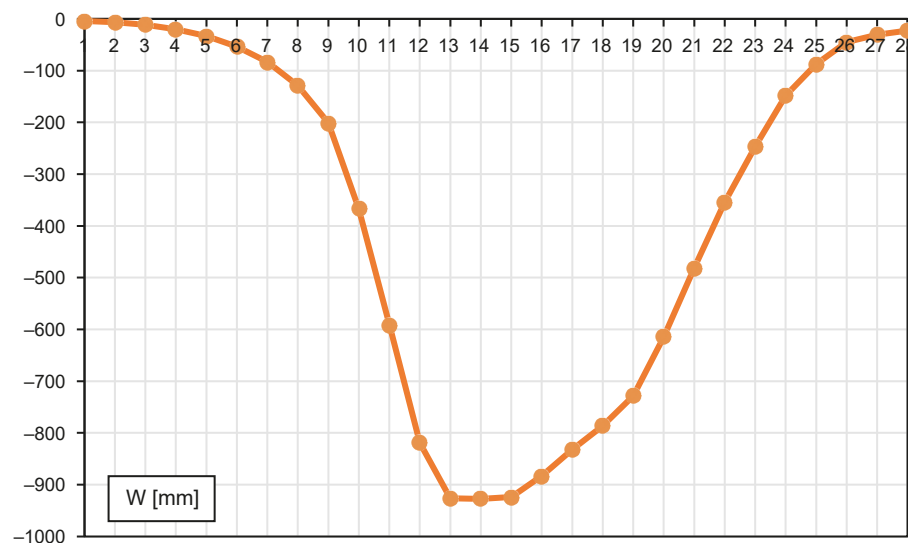


Figure 7. Waveform of the calculated subsidence [mm] of points of the measurement line "400 m"

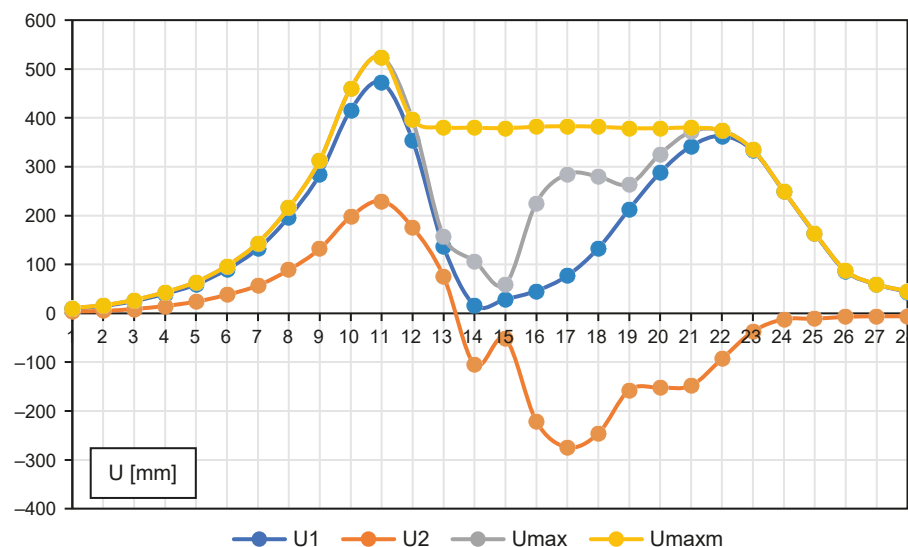


Figure 8. Waveforms of the calculated horizontal displacements [mm] (U1, U2 – horizontal displacement in the directions of the longitudinal and transverse axes of workings, Umax, Umaxm – final resultants and extreme in-time resultants) of points of the measurement line "400 m"

were subjected reached high maximum values in range IV and V of the influence category. However, they did not cause any significant reduction in the functionality of these workings nor, in principle, did they threaten the safety of their use.

Assessment of the influence range of mining exploitation in terms of determining the size of protective pillars for dog headings in the considered mining area

If mine workings are subject to mining influence, then the deformations occurring in them may result in the loss of their functionality or even dangerous damage to them (Duży & Kleta, 1998; Chudek et

al., 2011). Therefore, in such conditions, it is necessary to select and apply an optimal protective pillar of a size that ensures the safety and functionality of the workings protected by it. The size of the protective pillar should take into account the predicted size of the radius of influence scattering of the mining exploitation in the individual coal seams planned for exploitation.

The radius of influence scattering $r(z)$, which is the radius of influence range of mining in the rock mass, can be calculated from the dependence (Drzęzła, 1978):

$$r(z) = \frac{h}{\operatorname{tg} \beta(H)} \left(\frac{z + z_0}{h + z_0} \right)^n \quad (4)$$

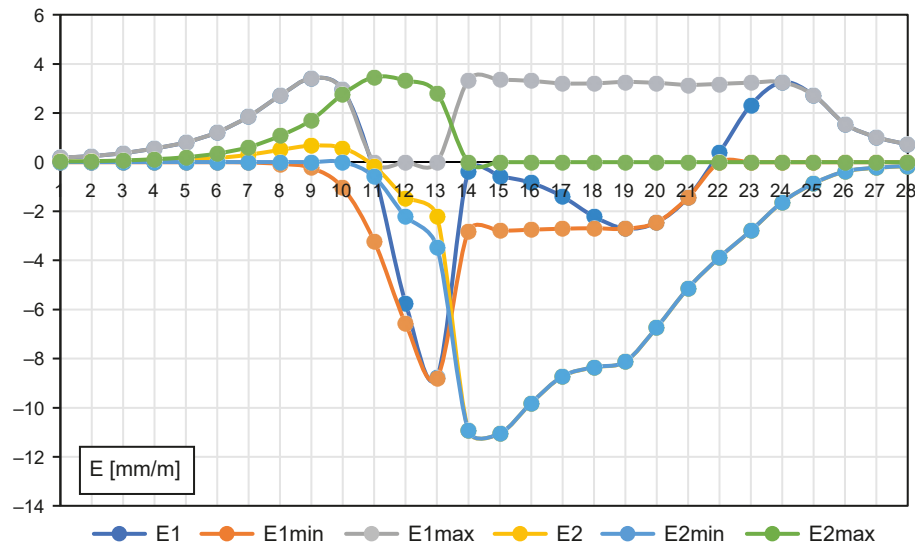


Figure 9. Waveforms of the calculated horizontal directional deformations [mm/m] (E1, E2 – final ones in the directions of the longitudinal and transverse axes of the excavations, E1min, E1max, E2min, E2max – extreme in time, minimum, and maximum in the directions of the longitudinal and transverse axes of the workings) at the points of the measuring line “400 m”

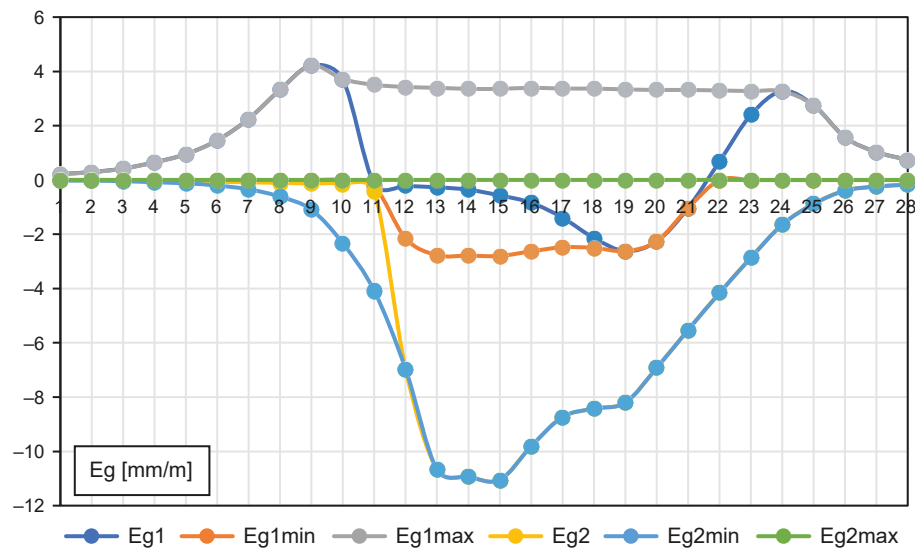


Figure 10. Waveforms of the calculated horizontal main deformations [mm/m] (Eg1, Eg2 – final values of the main deformations, Eg1min, Eg2min – values of extreme in time main minimum deformations, Eg1max, Eg2max – values of extreme in time main maximum deformations) at the points of the measuring line “400 m”

where:

h – depth of the mined element of bed surface dS ,
 $\operatorname{tg}\beta(H)$ – parameter of Knothe’s theory for surface ground, $\operatorname{tg}\beta(H) = 2.0$,

z – distance of the calculation point over the element ds ,

z_0 – parameter proposed by B. Drzęźła (Drzęźła, 1978),

n – exponent, where:

$n = 1$, $z_0 = 0$, by S. Knothe (Knothe, 1984),

$n = 0.5$, $z_0 = 0$, by J. Litwiniszyn (Litwiniszyn, 1954),

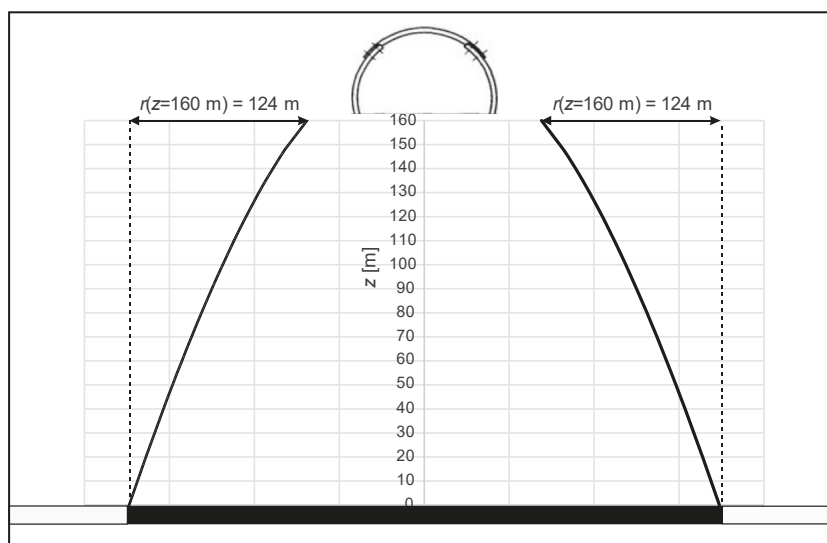
$n = 0.665$, $z_0 = 5ag$, by B. Drzęźła (Drzęźła, 1978).

The radius of mining exploitation influence range at vertical distance $z = 160$ m, calculated from Formula (4), corresponding to the location of Cross-cut I and Main Entry above longwall C-1 in seam 505wd, for the considered assumptions, is presented in Table 2.

Figure 11 shows graphically the size of the protective pillar for Cross-cut I and Main Entry, at which there would be no impacts of mining operations carried out in seam 505wd. To determine the required size of this protective pillar (Figure 11), we applied the range of mining exploitation influence effected by the exploitation of longwall C-1 in seam 505wd, determined by Formula (4).

Table 2. Calculated radius $r(z)$ of the influence range of mining in the rock mass at vertical distance $z = 160$ m above longwall C-1 in seam 505wd

By assumptions of S. Knothe (Knothe, 1984)	By assumptions of J. Litwiniszyn (Litwiniszyn, 1954)	By assumptions of B. Drzęźła (Drzęźła, 1978; Białek, 2003)
$r(z = 160 \text{ m}) = 84 \text{ m}$	$r(z = 160 \text{ m}) = 157 \text{ m}$	$r(z = 160 \text{ m}) = 124 \text{ m}$

**Figure 11. Protective pillar for dog headings located above seam 505wd**

Conclusions

The objective of the presented results was to verify data on the range of mining influence in a rock mass in an area of intensive mining operation on the basis of research on rock mass deformations at the location of dog headings. The determination of the values of the parameters of Knothe's influence theory the extensions proposed by J. Białek, on the basis of deformation measurements in the rock mass, taking into account the exploitation periphery and so-called far influences, can be used to determine the permissible range of panel length, thus ensuring the functionality of the protected dog headings and the optimization of stress concentration zones in terms of the risk of rock mass tremors.

The determination of the values of the parameters of the theory of influence and their mean errors was performed three times: for the entire measuring line and for its stabilized parts in Cross-cut I and Main Entry (i.e., in workings located at a vertical distance of approx. 160 m above longwall C-1 in seam 505wd).

The range of mining exploitation influence in the rock mass at the site of Cross-cut I and Main Entry is of particular importance for their functionality. If the influence range comprises these workings, then deformations caused by mining exploitation

may result in a loss of functionality of the workings or even in dangerous damage to them. The optimal size of the protective pillar for these workings should take into account the forecasted size of the radius of influence scattering of mining exploitation in the individual coal seams planned for mining operations.

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Economic aspects relating to machine operations on a mine main drainage system

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Abstract

This article presents an economic analysis of the exploitation of the main mine drainage according to the condition of machines. The study is based on actual operating data obtained during the operation of an underground hard coal mine. Through the selection of state estimators, appropriate sensory systems, as well as a long-term economic approach, operating procedures were developed that allowed for the introduction of significant financial savings. Operating costs are reduced by lowering energy consumption and reducing the costs of current repairs and spare parts. In addition to the classic approach to monitoring the state of a machine, based on the observation of residual processes, a global coefficient, referred to as unit energy consumption, has been proposed. Thanks to this, the operation of the machine occurs not only on the basis of its current dynamic state, but also due to the control processes of the machine's operation. Moreover, the article refers to the area related to water safety and the reliability of the pumping station.

Introduction

In underground mines, there is a seepage of groundwater, which poses a risk of flooding the mine (d'Obyrn, 2013). Drainage systems are built to protect against the effects of water inflow. Its main element is the primary drainage station, usually installed on the lowest level of the mining plant. Its task is to drain the water flowing into the mine,

which is collected in water galleries. Depending on the amount of incoming water and the depth of the foundation of the main drainage station, the operating costs vary within a vast range. In Polish mines, there is usually a moderate or high inflow of water and, in combination with considerable depths up to 1000 m, the operating costs of the main drainage are dominant (Bukowski, 2007). An important element influencing costs is the safety of the system, which

has a direct impact on the safety of the mining plant. The main costs of the drainage system are:

- Purchase of pumps, motors, pipelines, and other fittings;
- Installation of machinery, construction of waterways, construction of pipelines in the shaft, and construction of power lines;
- Consumables;
- Periodic inspections, service, and cleaning of sedimentation tanks;
- Running and major repairs;
- Renovation and main course;
- Direct service;
- Environmental fees;
- Technological security;
- Electricity.

The only utility product of the pumping station's operation is the safety of the underground mine and, moreover, the ability to excavate coal and other minerals. Thus, it is difficult to enter a cost-benefit-based account directly. Bearing in mind the main goal, which is water safety, it is possible to analyze the method of operating the drainage system together with its design and reliability calculations (Brzychczy, 2019). The presentation of possibilities for optimizing the operation of the main drainage system will be presented, based on the example of an operating underground coal mine in Poland.

Description of the research object

The main drainage system located at the shaft, at a level of 500 m in the analyzed underground coal mine, consists of ten pumping units installed in the pump chamber. The pump units are high-pressure pumps of the OW250/8 and WPWE-250/7LH types. Each pump unit is connected to two discharge pipelines with a diameter of 500 mm, which pump water to the surface. The pump units given in Table 1 were identified.

The water flow in the area of the main shaft pumping station is 20.22 m³/min, and the daily flow is 21,117 m³. The capacity of the waterways is 21,020 m³. In the case of stopping the pump station due to, for instance, power shortage or other failures, the time to fill the waterways is approximately 17.3 hours. A “2+1” (two are working, one is waiting) pump work program for a period of three months should be implemented in the pumping station. The “2+1” system means a continuous operation of two pumps and periodic connection of a third pump.

In the shaft there are 2 collectors, which transport water to the surface and the sedimentation tank. The

Table 1. Pumping station of the main drainage system of the primary mining plant

Assembly No.	Motor type	Pump type	Remarks
1	SCDdm 134 u	OW 250B/8	Technological considerations
2	SCDdm 134 u	OW 250AM/8	
3	S1 500X-4D	WPWE-250/7LH	
4	SCDdm 134 u	OW 250AM/8	
5	S1 500X-4D	WPWE-250/7LH	
6	SCDdm 134 u	OW 250AM/8	
7	Sh500 H4D	OW 250F/8	
8	S1 500X-4D	WPWE-250/7LH	Warranty repair
9	Sh500 H4D	OW 250AM/8	Renovation
10	Sh500 H4D	OW 250AM/8	Out of order

outer diameter of the collectors is 500 mm. The collectors are run in parallel, close to each other. The suction pipelines supplying water from the well to the pumps have a diameter of 300 mm, while the diameter of the discharge-side pipelines connecting the pumps with the collectors is 250 mm. The pumped water is very salty; therefore, it should be expected that the inner of the pipeline and/or collector is heavily corroded, which increases the flow resistance.

The main design assumptions were based on mining regulations and accounted for, among others, the following assumptions:

- The devices, together with the main drainage systems, should enable the discharge of the highest daily water inflow in a time not longer than 20 hours.
- If the pump chamber is equipped with pump units, the number of pumps in these units is at least:
 - 5 pumps – with 2 pumps working in a group,
 - 7 pumps – with 3 pumps working in a group.
- Main drainage devices should have at least two discharge pipelines, with a total capacity not less than the total rated capacity of the required number of installed pumps, at a flow velocity of not more than 3 m/s.

In the main drainage pumping stations, measurements were carried out that were necessary to perform the flow characteristics of the pumps (Zimroz et al., 2014; Korbiel, Biały & Czerwiński, 2016; Pawlik, 2020). The following were measured: volumetric in the manifold, pressure in the suction, and discharge nozzles, as well as the engine's electrical power. An ultrasonic flowmeter FlowKat 200 was used to measure the flux. Pressures were measured with dial gauges: vacuum with a vacuum gauge

using a range of 0.1–0 MPa and discharge pressure via pressure gauges with a measuring range of 0–8 MPa. Electric power consumption was determined with a SENTRON PAC3200 analyzer. The pumps were throttled by means of valves installed in the pipelines connecting the pumps with the main collector. In some pumps, it is possible to close the valves with actuators controlled from the supply cabinet; in the remaining pumps, the valves were closed manually. The valve opening degree was not known, but it was controlled by manual operation. Measurements were performed after establishing the flow conditions. After changing the degree of opening of the gate valve, the system worked for a few minutes and, after that time, the operating parameters were read. Measurements of pumping units no. 2, 3, 4, 5, 6, and 7 were carried out in the pumping station. The remaining units were under renovation or, for operational and technological reasons, were not active. The exemplary measurement results of pump 2 are presented in Table 2, while the collective results for the highest flow for all tested pumps are presented in Table 3. The measurement results were used to determine the total pressure (the pump head), power output, and pump efficiency.

On the basis of the measured values, the operating parameters were calculated (Skotniczny et al., 2010), which are presented in the tables. The pump head height, H_u , is determined from the relationship:

$$H_u = \frac{p_t - p_s}{\rho g} + \frac{c_t^2 - c_s^2}{2\rho g} + \Delta h_m \quad (1)$$

where p_s and p_t represent the pressure in the suction and discharge ports, respectively, c_s and c_t are the water velocity in the suction and discharge ports, respectively, and Δh_m is the height of the excess of the discharge pressure gauge in relation to the suction pressure gauge, $\Delta h_m = 0.6$ – 0.7 m.

The velocities in the suction and discharge nozzles are calculated using the volume flow of water and the cross-sectional area of the nozzles, i.e.:

$$c = \frac{Q}{A} \quad (2)$$

where c denotes the average water velocity in the nozzles, Q is the water volume flow, and A is the cross-sectional area, in which the diameter of the suction port $D_s = 300$ mm and the diameter of the discharge port $D_t = 250$ mm.

Table 2. Operation parameters of the pump unit no. 2

No.	Suction pressure	Discharge pressure	Stream	Electrical power	Speed at the suction port	Speed at the discharge port	Pump head	Power output	Efficiency of the pump unit	Pump shaft power	Pump efficiency
	p_s	p_t	Q	P_{el}	c_s	c_t	H_u	P_u	η_{zp}	P_m	η_p
	bar	bar	m ³ /min	kW	m/s	m/s	m	kW	[-]	kW	[-]
1	-0.47	50	8.4	1138	1.98	2.85	515.2	707.6	0.622	1081.1	0.654
2	-0.47	51	8.2	1132	1.93	2.78	525.4	704.4	0.622	1075.4	0.655
3	-0.47	52	8.1	1130	1.91	2.75	535.5	709.2	0.627	1073.5	0.661
4	-0.47	53	8	1128	1.89	2.71	545.6	713.6	0.633	1071.6	0.666
5	-0.46	54	7.9	1118	1.86	2.68	555.7	717.7	0.642	1062.1	0.676
6	-0.45	55	7.6	1117	1.79	2.58	561.4	697.5	0.624	1061.1	0.657
7	-0.44	56	7.3	1104	1.72	2.48	571.6	682.2	0.618	1048.8	0.650

Table 3. Cumulative operating parameters of the pump units

No.	Suction pressure	Discharge pressure	Stream	Electrical power	Speed at the suction port	Speed at the discharge port	Pump head	Power output	Efficiency of the pump unit	Pump shaft power	Pump efficiency
	p_s	p_t	Q	P_{el}	c_s	c_t	H_u	P_u	η_z	P_m	η_p
	bar	bar	m ³ /min	kW	m/s	m/s	m	kW	[-]	kW	[-]
2	-0.47	50	8.4	1138	1.98	2.85	515.2	707.6	0.622	1081.1	0.654
3	-0.48	48.4	9.8	1150	2.31	3.33	489.7	784.68	0.682	1092.5	0.718
4	-0.48	48.0	6.9	988	1.63	2.34	494.9	558.3	0.565	938.6	0.595
5	-0.48	46.4	10.2	1145	2.38	3.43	478.5	790.19	0.690	1087.8	0.726
6	-0.48	49	8.6	1185	2.03	2.92	505.1	710.23	0.599	1125.8	0.631
7	-0.48	48	8.9	1108	2.10	3.02	494.9	720.17	0.650	1052.6	0.684

Effective power, i.e., power transferred to the stream of pumped water, is determined from the relationship:

$$P_u = \rho g H_u Q \quad (3)$$

The efficiency of the pump unit is related to the power supplied to the electric motors, i.e.:

$$\eta_{zp} = \frac{P_u}{P_{el}} = \frac{\rho g H_u Q}{P_{el}} \quad (4)$$

The power on the pump shaft was found by accounting for the efficiency of the electric motor. A constant value of motor efficiency was assumed ($\eta_{sel} = 0.95$ for newer motors and $\eta_{sel} = 0.93$ for older ones). Pump shaft power is determined from:

$$P_m = \eta_{sel} P_{el} \quad (5)$$

and pump efficiency from:

$$\eta_p = \frac{P_u}{P_m} = \frac{\eta_{zp}}{\eta_{sel}} \quad (6)$$

Dependencies (1)–(6) were used to calculate the pump flow characteristics (Figures 1 and 2).

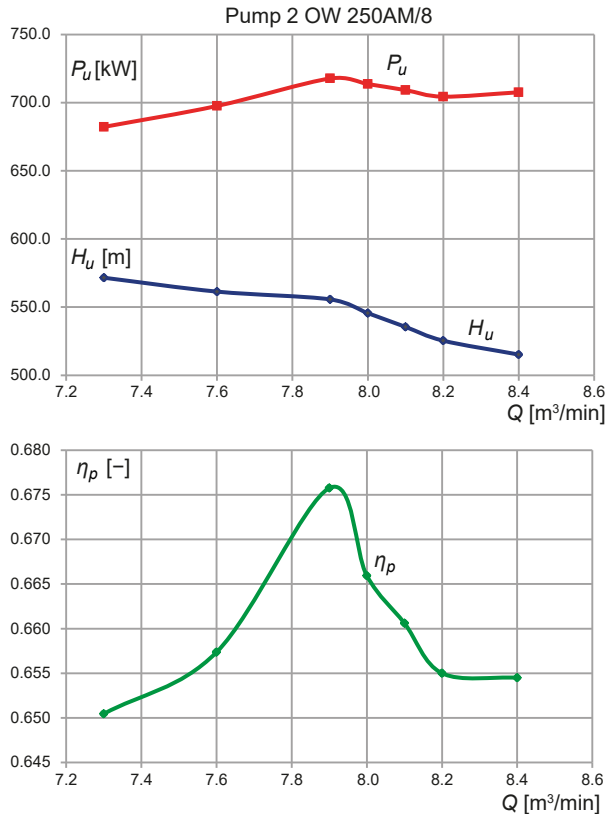


Figure 1. Flow characteristics of pump 2 – OW250AM/8: effective head $H_u = H_u(Q)$, useful power $P_u = P_u(Q)$, and pump efficiency $\eta_p = \eta_p(Q)$

The pump regulation range is small; it is a natural consequence of the purpose of the pumps and their primary role in the mine drainage. The pumps operate with full openings of the valves in order to minimize energy losses resulting from flow resistance, which shortens the operation time. The highest value of the water volumetric corresponds to the normal operation of the pump, i.e., when the valves are fully open (Michlowicz & Wojciechowski, 2021).

Table 4 presents the results of measurements and calculations of the pump operation parameters at full opening of the valves. This state corresponds to the highest efficiency of the pumps and a lack of throttling of the flow. The energy losses occurring in the transport of water under these conditions correspond to the flow resistance that results from the configuration and geometry of the pipeline system. The tables also include the relative pump head, defined as the ratio of the effective head in real conditions, H_u , to the catalog head of the pump, H_{uk} , at the same flow. The values of this fraction can be interpreted as a measure of the correctness of the pump selection for the task of lifting water to the required height. Calculating the ratio value H_u/H_{uk} allows us to determine whether the pumps are correctly matched to the requirements of the pumping system. The H_u/H_{uk}

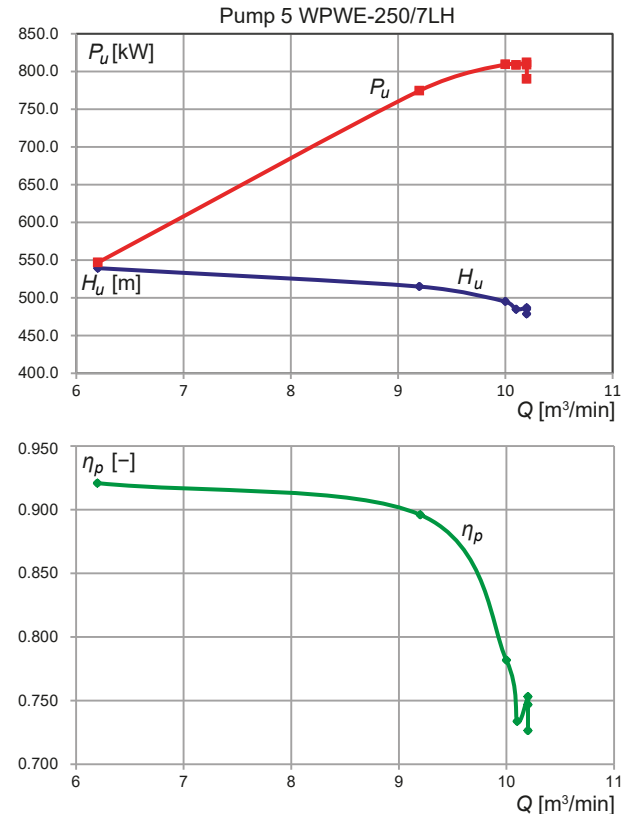


Figure 2. Flow characteristics of pump 5 – WPWE-250/7LH: effective head $H_u = H_u(Q)$, useful power $P_u = P_u(Q)$, and pump efficiency $\eta_p = \eta_p(Q)$

value at the level of 0.93 for the pumping station indicates a slight degree of oversizing of the pumping system (Tajduś et al., 2017).

The value of the fraction of the efficiency factor, η_p , to the catalog efficiency, η_{pk} , of the pump at a steady stream of water can be taken as a measure of the quality of the pump condition. The lower the value of this ratio, the worse condition of the pump in its operation. The pumps operating in the pumping station have a value of this ratio above 0.82, while the average value for all pumps is 0.85, which means that the pump quality can be interpreted as good (Janus, Skotniczny & Richert, 2019).

Table 4 also shows the coefficients determining the energy consumption of the pumps, q_P , and the costs of water pumping, q_E . The q_P factor indicates the amount of electricity in kWh required to pump out 1 m³ of water. On the other hand, the q_E coefficient determines the cost of pumping 1000 m³ of water at a price of PLN 280/MWh.

For pumps operating in the pumping station, the energy consumption of the process is $q_P = 1.873$ – 2.387 kWh/m³; the average value is $q_P = 2.155$ kWh/

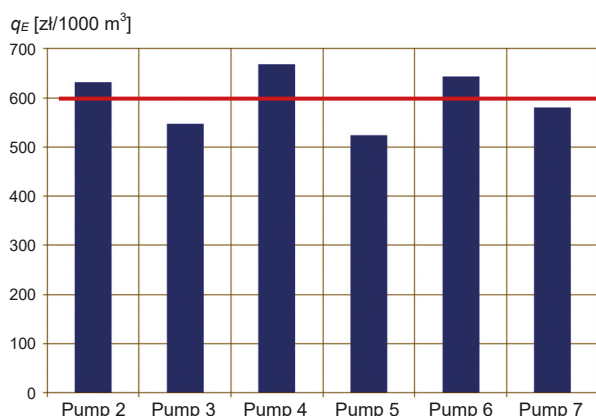


Figure 3. Cost of pumping 1000 m³ of water in the pumping station

m³. The costs of pumping out 1000 m³ of water in the pumping station are $q_E = 524$ – 668 PLN/1000 m³, while the average value is $q_E = 600$ PLN/1000 m³. The costs of pumping water are also shown in Figure 3; here, the red line is the average value for the main drainage pumping station in the shaft. In Table 4, the yellow highlighting indicates the estimated values of the energy consumption coefficient and unit costs in the situation of pump operation with catalog head and pump efficiency at measured water streams (Korbiel & Wojciechowski, 2019).

Analysis of the work of pumping units

Ten pump sets are used for the main drainage (engine – multi-rotor pump). The sets work with 100% redundancy – in a parallel system (Białecka & Prażak, 2019). The diagram of Figure 4 shows a list of ten pumps marked from P1 to P10.

The capacity of the water galleries is 22,020 m³ (i.e., after about 18 hours, when the pumps are not working, flooding of the underground galleries occurs). Water seepage to the mine is 20.22 m³/min; i.e., 1213.2 m³/h on average approximately 873,500 m³/month. The pump capacity determined in the tests is on average 8.6 m³/min, i.e., 516 m³/hour. Thus, there is a need for 2.35 pumps, i.e., approximately 1690 hours of pump operation/month (Table 5 – column SUM). The operating times of individual pumps during the year are summarized in Figure 5.

Determination of the efficiency of pumping sets

A diagram of the relationships that determines the efficiency is shown in Figure 6, while the results of the calculations are presented in Table 6 (Zgrzebski, Laskowski & Danis, 2022).

Table 4. List of pump operation parameters at maximum efficiency

		Pump 2	Pump 3	Pump 4	Pump 5	Pump 6	Pump 7	Mean
Volume flow, Q	m ³ /min	8.4	9.8	6.9	10.2	8.6	8.9	8.8
Useful lifting height, H_u	m	515.2	489.7	494.9	478.5	505.1	494.9	496.7
Relative lift height, H_u/H_{uk}	–	0.93	0.99	0.82	0.98	0.92	0.92	0.93
Electric power, P_{el}	kW	1138	1150	988	1145	1185	1108	1119
Pump efficiency, η_p	–	0.654	0.718	0.595	0.726	0.631	0.684	0.668
Relative pump efficiency, η_p/η_{pk}	–	0.87	0.86	0.82	0.87	0.84	0.92	0.85
Electricity consumption, q_P	kWh/m ³	2.257	1.957	2.387	1.873	2.299	2.075	2.155
Cost of pumping water, q_E	zł/1000 m ³	632	548	668	524	644	581	600
Electricity consumption, q_{Pk}	kWh/m ³	2.119	1.690	2.642	1.675	2.090	2.048	2.005
Cost of pumping water, q_{Ek}	zł/1000 m ³	593	473	740	469	585	574	561

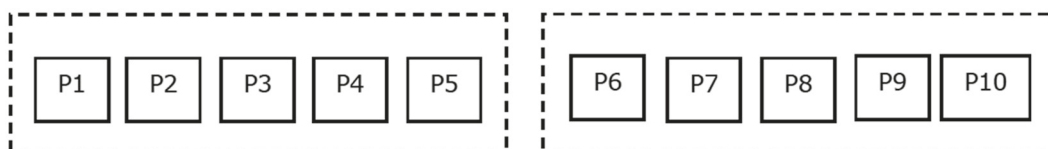


Figure 4. Scheme of parallel redundancy of the main pumping station

Table 5. Example of an annual summary of the use of pumps

Month	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	SUM
Working time [hours]											[hours]
I	bd	bd	bd	bd	bd	bd	bd	bd	bd	bd	
II	233	0	65	0	0	508	45	0	725	7	1583
III	5	1	8	0	153	50	5	621	50	662	1555
IV	0	0	0	0	169	0	42	734	0	727	1672
V	0	0	72	35	611	49	44	85	610	125	1631
VI	0	355	108	0	344	0	37	0	551	98	1493
VII	0	714	742	0	0	35	43	0	0	95	1629
VIII	0	695	578	0	9	3	40	62	0	160	1547
IX	0	696	94	0	74	0	13	744	0	350	1971
X	0	647	0	0	173	1	8	603	0	178	1610
XI	0	34	0	710	134	0	22	34	0	713	1647
XII	0	0	0	725	190	0	0	0	0	722	1637
SUM	238	3142	1667	1470	1857	646	299	2 883	1936	3837	17,975
Average/month	21.6	285.6	151.4	133.6	168.8	58.7	27.2	262.1	176.0	349	1634.1

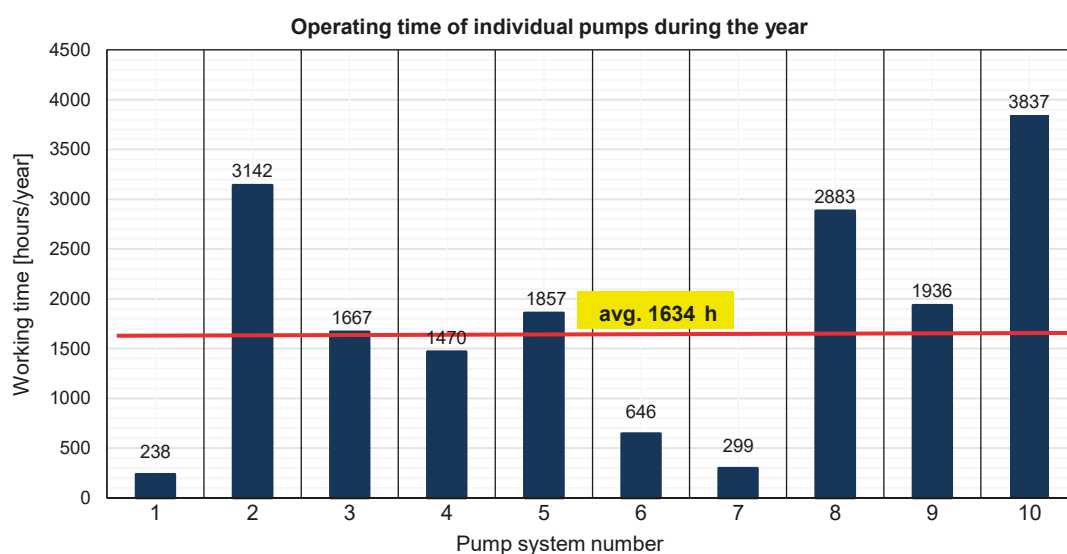


Figure 5. Diagram of the operation times of the P1 – P10 pump units

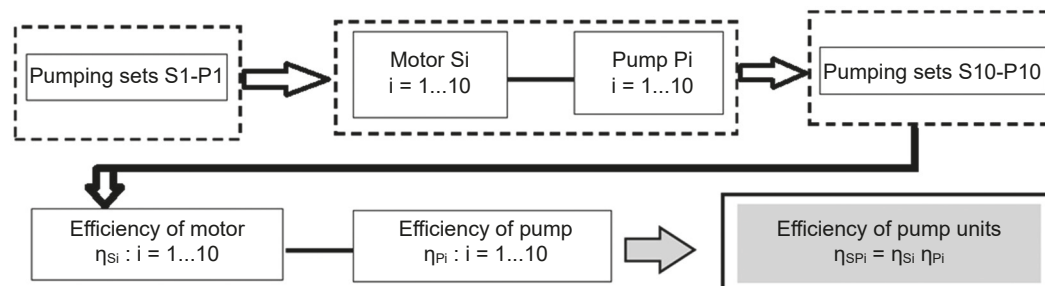


Figure 6. Scheme for determining the efficiency of pump units

Table 6. Efficiency of the pumping units in the pumping station

No.	Set	Pump efficiency	Set efficiency [%]
1	Pump No. 1	0.65	62
2	Pump No. 2	0.52	49
3	Pump No. 3	0.69	65
4	Pump No. 4	0.59	56
5	Pump No. 5	0.73	69
6	Pump No. 6	0.63	59
7	Pump No. 7	0.68	65
8	Pump No. 8	0.59	56
9	Pump No. 9	0.66	63
10	Pump No. 10	0.68	65

Economic evaluation of the operation of main drainage pumps

The operating costs, K_{exp} , are the sum of all costs related to the operation of the pump units, i.e.:

$$K_{exp} = K_{zak} + K_E + K_{ob} + K_{deg} \quad (8)$$

where K_{zak} , K_E , K_{ob} , and K_{deg} are the purchase, energy, service, and degradation/repair costs, respectively.

The purchase costs constitute the cost of installing a complete set consisting of an engine with elements of electrical equipment for pumps, foundation system, and installation. The purchase value depends on the selection of the system, manufacturer, method of operation, etc. For further analysis, the value of $K_{zak} = \text{PLN } 1,000,000$ was adopted, which is an indicative value. The full-service life of the set was also assumed, amounting to 15 years of operation. This value is mainly related to the operating parameters of the engine. The pledge efficiency of $8 \text{ m}^3/\text{min}$ was also assumed; the requirement is 2.5 pumps.

The cost of electricity was assumed to be the full load of the system. Considering the engine power of

1250 kW and the assumed electricity price of PLN 380/MWh, the energy cost is PLN 475/h, i.e., PLN 4,161,000 per year. It should be noted that due to the dynamically changing environment, the price of electricity fluctuates significantly, especially at the turn of 2021 and 2022 (d'Obyrn, 2013).

The cost of service was assumed to be the average remuneration amounting to PLN 6,000 per month (the employer's cost, i.e., including tax, for which all contributions are paid to the Social Insurance Institution and contributions to PPK or PPE). The worker operates all the pumps in the pumping station. The calculations ignored the increase in the minimum wage in the analyzed period.

The cost of degradation includes all the expenses related to the reconstruction of the technical condition of the pump unit. The most dynamic degradation process is observed at the pump. Its elements are subject to wear, which can be regenerated or replaced. Based on the analysis of the available materials, the cost of pump renovation was assumed to be PLN 300,000. Also supposed is an average time between renovation of 10,000 h (i.e., approximately 14 months). The operating costs should include the costs of engine degradation (replacement of bearings), the cost of lubricants, the replacement of seals, etc. These costs were assumed to be the amount of PLN 5000 per year.

Scenario I

The total cost of operating one pump is shown in Table 7. It has been assumed that the pump will operate continuously throughout its lifetime, i.e., 15 years.

It should be noted that the total cost of operation is mainly determined by the cost of electricity (92.09%). For the purposes of this analysis, a pledge expenditure at $8 \text{ m}^3/\text{min}$ for one pump was assumed. Assuming full efficiency, the pump will pump

Table 7. Pump operating costs in scenario I

Operating cost component	Cost	Share in total cost	Remarks
K_{zak}	1,000,000 zł	1.47%	–
K_E	62,415,000 zł	92.09%	Annual energy cost – PLN 4,161,000.
K_{ob}	432,000 zł	0.64%	Annual cost of servicing 2.5 pumps – PLN 1,080,000. An employee operates 2.5 pumps.
K_{deg}	3,932,145 zł	5.80%	14 months – time between subsequent renovations. Renovation cost for 1 year: PLN 257,143. Annual other degradation costs – PLN 5000.
Total	67,779,145 zł	100.00%	–

Table 8. Pump operating costs in scenario II

Operating cost component	Cost	Share in total cost	Remarks
K_{zak}	1,000,000 zł	2.89%	–
K_E	31,207,500 zł	90.08%	Annual energy cost – PLN 4,161,000.
K_{ob}	432,000 zł	1.25%	Annual cost of servicing 2.5 pumps – PLN 1,080,000. An employee operates 2.5 pumps.
K_{deg}	2,003,571 zł	5.78%	14 months – time between subsequent renovations. Renovation cost for 1 year: PLN 257,143. Annual other degradation costs – PLN 5000.
Total	34,643,071 zł	100.00%	–

4,204,800 m³ per year, i.e., 63,072,000 m³ during 15 years of operation. Considering the adopted assumptions and the costs included in Table 7, the cost of pumping out 1 m³ is PLN 1.07.

Scenario II

The total cost of operating one pump is shown in Table 8. It has been assumed that the pump will operate continuously throughout its service life, i.e., 15 years, and the pump load will be 50%.

Assuming a pledge expenditure of 8 m³/min for one pump with 50% efficiency, the pump will pump 2,102,400 m³ per year, i.e., 31,536,000 m³ during 15 years of operation. Taking into account the adopted assumptions and the costs included in Table 8, the cost of pumping out 1 m³ is PLN 1.10.

Assuming the required total flow rate of 20 m³/min, a load of 2.5 for the pump is necessary. Accounting for the costs of operating the pumps presented in scenarios I and II, the total cost of the pumping station's operation over a period of 15 years will amount to PLN 170,201,361. In turn, the annual cost of the pumping station, consisting of 3 units, will amount to PLN 11,346,757.43.

The conducted analyzes show that the cost of operation is mainly determined by the cost of

electricity – it accounts for over 90% of the total cost. The cost of electricity depends on the price and the efficiency of the pump unit. Therefore, actions aimed at improving efficiency should result in a significant improvement in the financial results.

The energy needed to pump out 1 m³ is $1000 \text{ kg} \times 9.81 \text{ m/s}^2 \times 500 = 4.9 \text{ MJ} = 1.36 \text{ kWh}$. Therefore, for different efficiencies, the energy consumption of the process has the values presented in Table 9.

Conclusions

The conducted research and analyzes have shown that the dominant cost of operating the drainage of the main underground coal mine is the cost of electricity. The amount of energy in relation to the amount of water pumped out depends on the efficiency of the pumping machines. The introduction of energy indicators made it possible to determine the unit operating costs of the pumping station. Considering the electricity prices, a 10% efficiency improvement can reduce costs equivalent to buying new equipment. Thus, the continuous analysis of the efficiency of machines, in conjunction with the optimal scenarios of the system operation, can significantly reduce the overall operating costs. The recommendations presented in the article were implemented in one of the mines. Preliminary economic data show the effectiveness of the proposed solutions.

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Table 9. Energy consumption and the annual cost of electricity for the process

Efficiency	Energy consumption in PLN/m ³	Annual cost of electricity (20 m ³ /min)
100%	0.52	5 466 000
80%	0.65	6 833 000
75%	0.69	7 253 000
70%	0.74	7 779 000
65%	0.80	8 410 000
60%	0.87	9 145 000
55%	0.95	9 986 000
50%	1.04	10 933 000

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Power Engineering

Possibilities of recovery of fine-fraction energy waste from fluidized bed boilers in underground mining for liquidation of underground workings

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JEL Classification: Q55, Q57, Q59

Abstract

Currently, the Polish power industry is mainly based on solid fuels, such as hard coal and lignite, and there is a problem with the management of significant amounts of combustion waste. One of the directions of recovery of these types of waste is underground hard coal mining operations, where the general problem of their management is the variability of physical and chemical properties resulting from the combustion of fuels of different parameters in power boilers with different exhaust gas cleaning solutions, mainly desulphurization methods. One of the solutions for energy production currently in use is the combustion of coal in fluidized bed boilers, in which the so-called dry desulfurization method is adopted. As a result of this process, a fine-fraction waste with the European code 10 01 82 is created, which is characterized by pozzolanic features, enabling its use wherever specific strength parameters are expected from the material. One such technology is the liquidation of underground workings based on the pouring of a hydro-mixture into the fenced-off space of the workings using a gravity-fed pipeline. The space to be filled is fenced off by closing it on both sides with dams, usually made of brick walls, located at an appropriate distance. It should be taken into account that the hydro-mixture will tend to slow the sedimentation of solid particles on the spreading path, and working may have a variable slope. The paper presents the results of laboratory tests of the physical and mechanical properties of hydro-mixtures made on the basis of selected energy waste from a fluidized bed boiler, along with a practical example of its application for the liquidation of underground workings.

Introduction

For many years, Polish hard coal mines have been using large amounts of waste materials, including fine-fraction energy waste in the form of hydro-mixtures in various underground mining technologies. These include the sealing of goafs, construction of dams, and filling plugs or liquidation of underground voids (Plewa & Kleta, 2001; Plewa & Mysłek, 2001; Plewa, Popczyk & Mysłek, (2007). The use of ash-water hydro-mixtures in underground mining

is legally regulated by the ordinance of the Minister of the Environment (Regulation, 2015) issued with the Waste Law (Legal Act, 2012) and has the legal form of waste recovery. In addition, the required physical and mechanical properties of hydro-mixtures are defined in the standard PN-G/11011:1998, which is not binding but, due to the lack of other standard-specific regulations, is widely recommended and used in ore and hard coal mining. Currently, the energy waste market is dominated by such products since various fly ashes captured in electrostatic

precipitators have the codes 10 01 02 and 10 01 82 (Popczyk, 2017a). The ashes with the code 10 01 02 are fly ashes from coal produced in conventional boilers without the desulphurization processes. Their use in underground mines, due to the lack of binding properties, is possible only in fire prevention for sealing goafs or filling sub-level workings and post-mining voids. In addition to mining, these types of waste are widely used in the construction industry to produce building elements, cement, and concrete.

According to the assumptions of the Polish government, the Polish hard coal mining industry is currently undergoing another phase of transformation that consists of a slow liquidation of the hard coal mining in Poland until the year 2049. The decommissioning process of a mining plant is, in practice, a very complex issue and includes, among others, the liquidation of underground workings, which in some justified cases requires, among others, tight filling of liquidated spaces. Considering the significant amount of underground workings intended to be liquidated by filling them in, it is reasonable that the filling material should be cheap and widely available. Due to the fact that the combustion of hard coal generates a significant amount of fine-fraction energy wastes obtained from electrostatic precipitators and various desulphurization methods installed

in power plants, these wastes are commonly used in underground workings in various mining technologies, including the liquidation of underground workings. This technology is based on the introduction of a fine-fraction hydro-mixture into the fenced-off space of the underground excavation, which often has binding properties, using a gravity-fed pipeline system. An exemplary diagram of the technological process of using fine-fraction energy waste to liquidate underground workings is shown in Figure 1.

This solution is characterized by the fact that the mixing station for the preparation of hydro-mixture is built on the ground surface, which is not always close to the backfilling shaft or the opening into which it is fed. The energy waste delivered with road tankers is discharged pneumatically to the storage silos or directly into the mixer, which is also fed with water. The method of preparing the mixture with appropriate physical and mechanical parameters must be performed in an accurate and repeatable manner, i.e., the structure of the mixer must ensure a high mixing accuracy of the hydro-mixture with smooth adjustment of batching of the components. The installation is equipped with monitoring devices, such as flow meters, and a density gauge to regulate the batching process of components, which automatically respond to the readings of the density

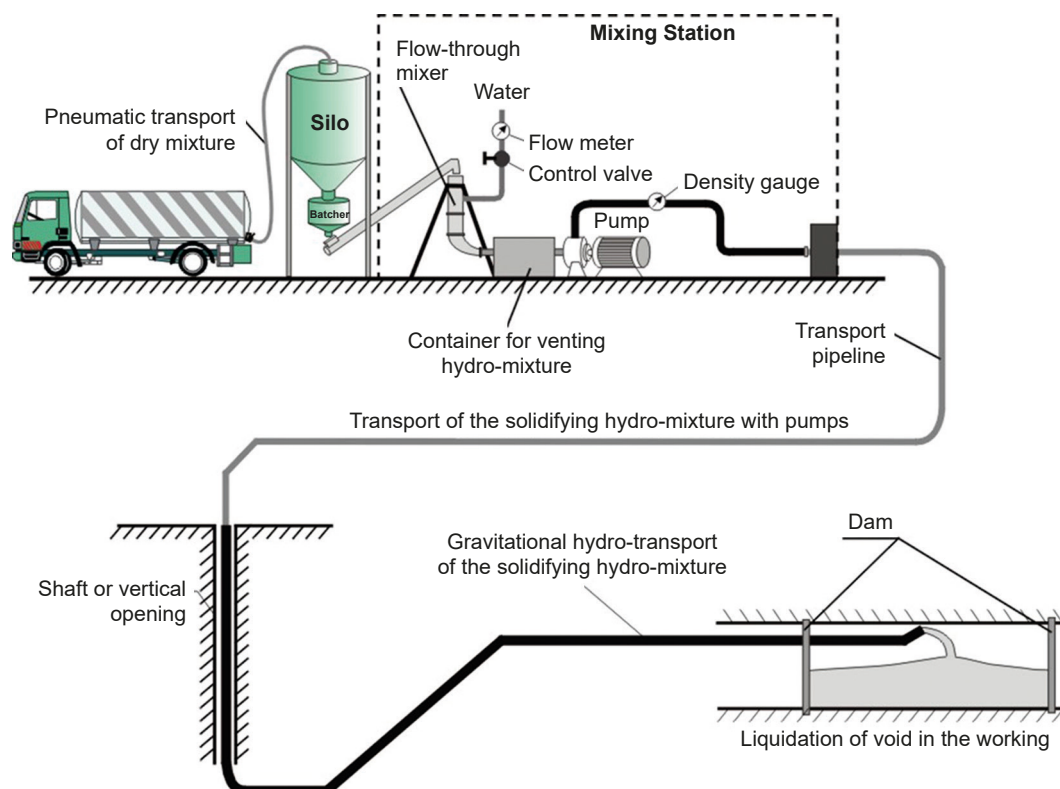


Figure 1. Diagram of the installation for the use of energy waste for liquidation of underground workings with the mixing unit placed on the surface

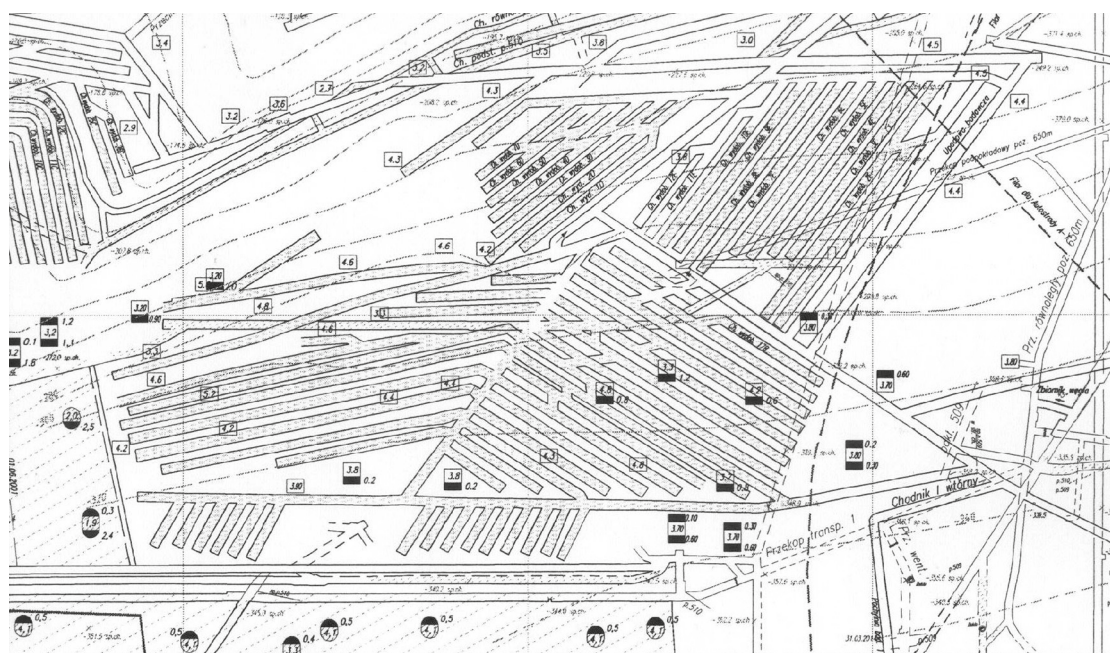


Figure 2. An example of coal seam mining with galleries and their liquidation by filling

gauge of the ready hydro-mixture. The installation is also equipped with a pump for forcing the finished hydro-mixture from the retention tank to the backfilling pipeline. This solution is characterized by a good preparation accuracy of the backfilling mixture, without an unnecessary amount of excess water, and it is recommended when the mixtures are used in technologies in which it is necessary to obtain appropriate values of rheological parameters, as well as subsequent strength parameters for the solidified hydro-mixture (Popczyk, 2018; 2020).

One of the backfilling examples of dog headings, created after hard coal mining operations, with ash-water mixtures is the exploitation of the seam with a thickness of approximately 4.0 m, as shown in Figure 2. The backfilled workings were bored with the use of AM-50 road headers, leaving pillars and solid coal between them with a width of 4 m to 6 m. The operating headings were designed to allow their maximum backfilling with hydro-mixtures and the outflow of excess water.

Formation and use of fluidized ashes

With respect to the fine-fraction energy wastes from the 10 01 82 group, the dominant group is composed of ash produced in the process of burning fine coal in fluidized bed boilers. Experience has shown that the resulting fluidized ashes are characterized by much improved pozzolanic properties compared to other ashes obtained from the method applied in fluidized bed boilers, referred to as so-called dry

desulfurization in a fluidized bed (Popczyk, 2016). Currently, many boilers in the power industry use the so-called “fluidized combustion”, and the ashes produced in them differ significantly in their physical and chemical properties, depending on the place of their formation.

Amid larger power plants located in the province of Silesia Voivodship, fluidized combustion is used, among others, in Power Plant “Jaworzno”, “Siersza”, or “Łagisza” and in Heat and Power Plant “Chorzów” or “Katowice”. The main advantages of combustion in fluidized bed boilers include:

- the possibility of using sludge from coal enrichment installations as fuel,
- simple preparation of fuel for combustion and simple fuel supply to the combustion chamber,
- significant (80%) reduction of SO₂ emissions to the atmosphere by supplying sulfur-binding compounds to the deposit,
- low nitrogen dioxide emissions due to the low temperature of the deposit (850 °C),
- high combustion efficiency due to turbulent mixing and the long residence time of particles in the circulation bed.

The main disadvantages of the fluidized bed combustion technology include:

- long start-up process from the cold state due to a large ceramic mass (6.5–7 h),
- much higher air pressure is needed for combustion compared to pulverized coal boilers, due to a higher flow resistance and the need to maintain a fluidized bed.

Ashes from fluidized bed boilers, due to their binding properties, are currently widely used for the production of mineral binders used, for example, in underground mining (Plewa, Popczyk & Piontek, 2009; Regulation, 2015). Such binders have guaranteed strength properties obtained by their stabilization resulting from the share of cement and enhancing additives. The use of such products in underground mines is justified when the specific technology requires the acquisition of sufficiently high and stable strength parameters in the position of their placements, such as an insulating plug, explosion-proof plug, or water dam. Otherwise, when the technology does not require stable high-strength parameters, it is possible to use hydro-mixtures made on the basis of ash from fluidized bed boilers only (Popczyk, 2021). An example of such an application is the use of ash-water hydro-mixtures for the liquidation of workings and underground voids. In this case, the ash-water hydro-mixtures should be characterized by (PN-G-11011:1998; Plewa & Kleta, 2001; Popczyk, 2017b):

- a significant range of spread,
- the smallest possible amount of seep (excess) water,
- binding and strength properties in a low range,
- resistance to soaking (action of groundwater).

From the point of view of the binding process and the final strength parameters, the proportion of water in the mixture should be optimized in terms of the effectiveness of the hydration process. However, because the mixtures are delivered hydraulically to the places of their application by means of gravity pipeline transport systems, the amount of water in the mixture is usually greater than when it results from the above-mentioned criteria, and it must consider the likelihood of such transport (Popczyk, 2017b). The optimization of the hydro-mixture composition must, therefore, account for both the previously mentioned requirements regarding the binding course and strength after solidification, as well as the needs regarding the flow conditions in the transport installation and the subsequent spread in the excavation.

Methodology and laboratory tests of hydro-mixtures on the basis of fluidal ashes

The tests of the hydro-mixtures, prepared on the basis of the selected wastes (coded as 10 01 82) in the form of fluidized ashes, were performed in the laboratory of the Department of Geoengineering and Raw Materials Exploitation in line with PN-G-11011.

The research included the determination of the following selected parameters:

- S/W mass share (dry ash/water) and density,
- amount of excess water,
- compressive strength,
- soakability.

To show the variation in the physical and mechanical properties, which result from the different proportions of mixing water in the hydro-mixture with fluidized ash, laboratory tests of the hydro-mixtures were carried out for different S/W ratios (dry ash/water). To obtain the appropriate flowability of the mixture, which determines its physical properties, water was added to dry ashes in the amount necessary to obtain a specific consistency, defined by the standard of table spread of the mixture. To better visualize the differences in the tested parameters, depending on the proportion of water in the hydro-mixture, six different consistencies of hydro-mixtures were adopted, determined by the table spread parameter in accordance with PN-G-11011, with the values of 160, 180, 200, 220, 240, and 260 mm used.

The rise in the table spread of the mixture is achieved by increasing the proportion of water in the mixture. The effect of increasing the proportion of water is that the concentration of the solids is reduced, the density of the mixture is lessened, the viscosity is lowered, the binding time is extended, and the strength properties of the solidified mixture deteriorate; moreover, in an extreme case, it even results in the loss of its solidification capacity. Mixtures with the table spread below 200 mm are characterized by a more compact consistency, increased hydrotransport resistance, higher values of strength after solidification, and a smaller amount of excess water. From the viewpoint of hydrotransport, the mixture with a lower concentration of solids (table spread above 200 mm) ensures lower flow resistance in the installation and, hence, higher flow velocity and a greater range of hydrotransport. This is especially important in the case of a significant horizontal distance from the backfilling shaft to the work sites, or a small difference in levels between the ground surface and the position of the backfilling works. On the other hand, a mixture of high table spreads contains much more water than that which can be found by fly ashes contained therein. This water, known as over-sludge water, flows out of the place where the hydro-mixture is placed and merges with mine waters and may contribute to a possible increase in the water hazard. Taking the above into account, one should always attempt to optimize hydro-mixture composition in terms of the proportion of over-sludge water.

As mentioned earlier, in laboratory conditions, hydro-mixtures based on fluidized ash were made for six different proportions of ash-to-water mass, which provided hydro-mixtures with six table spread levels from 160 to 260 mm. After the hydro-mixtures had been prepared, the density and the amount of over-sludge water were determined; the results are summarized in Table 1. Simultaneously, samples were prepared from those hydro-mixtures for future strength tests.

Table 1. Designated selected physical properties of hydro-mixtures made on the basis of ash from a fluidized bed boiler

S/W proportions	Density [kg/m ³]	Table spread [mm]	Amount of over-sludge water [%]
1:0.75	1452	160	2.4
1:0.85	1434	180	4.2
1:1.00	1422	200	6.9
1:1.05	1411	220	9.1
1:1.12	1398	240	13.3
1:1.20	1386	260	16.2

As can be observed from the conducted research, along with the increase in the proportion of water in the composition of the mixture, its table spread increases and its density decreases. With a rise in the table spread in the range from 160 to 260 mm, the density of the mixtures decreased from 1452 to 1386 kg/m³, while the S/W mass ratio increased from 0.75 to 1.20.

The amount of over-sludge water that flows out of the hydro-mixture, at the place where it is located, is in the range of 2.4 to 16.2%. The highest amount of over-sludge water (i.e., 16.2%) was contained in the hydro-mixture with the highest proportion of water and the highest table spread of 260 mm. The smallest amount of over-sludge water (i.e., 2.4%) was contained in the hydro-mixture with the smallest water content and the smallest table spread of 160 mm.

The tests of uniaxial compressive strength R_c of the hydro-mixtures, made on the basis of fluidized ash, were carried out after 7, 14, 28, and 60 days. To reproduce the typical climatic conditions in the underground workings of mines, the samples of the mixtures were seasoned in the LTB 650 RV climatic chamber made by Elbanton in the following storage conditions: temperature 25°C and humidity 95%. Additionally, after 60 days, the samples were soaked with water for 24 hours to determine their soakability, i.e., the degree of strength loss R_c . The results of those tests are summarized in Table 2 and Figure 3.

Table 2. Strength to uniaxial compression, and the slakeability of hydro-mixtures, prepared on the basis of selected fluidized ashes depending on their table spread

Table spread of hydro-mixture	Strength R_c [MPa]					Slakeability K [%]
	7 days	14 days	28 days	60 days	R_c 60 + 24 h of water soaking	
160	0.48	1.25	2.85	3.52	3.25	7.7
180	0.42	1.22	2.68	3.33	3.02	9.3
200	0.32	1.08	2.45	3.15	2.77	12.1
220	0.26	0.98	2.21	3.08	2.54	17.5
240	0.19	0.83	1.92	2.89	2.26	21.8
260	0.15	0.74	1.75	2.58	1.93	25.2

The resistance tests on uniaxial compression of samples made in laboratory conditions showed that, with an increase in the seasoning time in the climatic chamber, the R_c resistance grows. Additionally, it can also be seen that the resistance R_c decreases along with an increase in the table spread of the hydro-mixture. After seven days of seasoning in a climatic chamber, the resistance of the hydro-mixtures fell for the table spread range from 160 to 260 mm, since it dropped from 0.48 to 0.15 MPa, respectively. After 14 days, with the same spread table range, the R_c resistance decreased, ranging from 1.125 to 0.74 MPa. After 28 days, it was from 2.85 to 1.75 MPa and, after 60 days, it was from 3.52 to 1.93 MPa.

All tested samples, after 60 days of seasoning in a climatic chamber and 24 h soaking in water, showed a specific loss of R_c resistance. It was also noticed that, with the increasing table spread, the loss of resistance was greater. The lowest slakeability value of 7.7% was recorded for the hydro-mixture with a table spread of 160 mm, while the highest slakeability of 25.2% was found for a table spread of 260 mm.

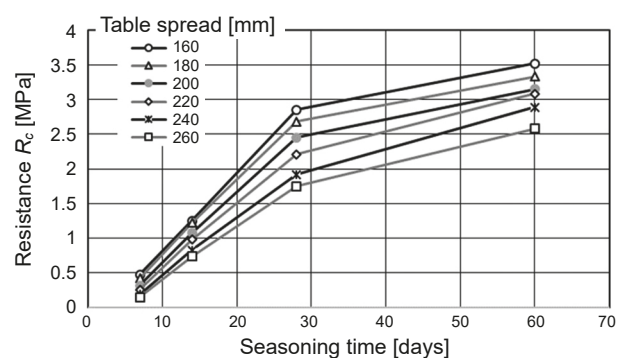


Figure 3. Resistance to uniaxial compression of hydro-mixtures over time, based on fluidized bed boiler ash for different table spreads

Liquidation of underground workings with fine-fraction hydro-mixtures

The liquidation of underground workings by their backfilling is mainly associated with the construction of dams with appropriate strength parameters and backfilling of the fenced-off space; thus, their creation is most often with binding mixtures. The construction of dams with an adequately durable structure is particularly important when filling the free space with hydro-mixtures made of waste materials, where it is difficult to lead the water away in contrast to backfilling materials (i.e., sand and stone), and they trigger a different course of pressure changes affecting the dam structure over time. This is becoming particularly important when filling the workings of extensive length and greater slope, which requires the so-called partial filling in stages. The separating or backfilling dams made in mines are significantly diversified in terms of construction, material consumption, and labor, which affects their strength properties. The methods of building these dams most often result from the traditions and experiences gathered by individual mines.

The load-bearing structures of the separating or backfilling dams may be loaded with the following:

- the hydrostatic pressure of the mixture,
- the dynamic pressure of the liquid mass,
- additional load resulting from adding waste material in the case of using wastes or their mixtures.

The fencing-off of the working excavation space, which is then backfilled with hydro-mixture, is made by damming the excavation on both sides with brick dams, usually made of concrete blocks on cement mortar, located at an appropriate, defined distance from each other. The basic problem is to determine the optimal distance between the dams from the viewpoint of expenditure, so that the liquidated space is completely filled, taking into account that the fed material will have a liquid-plastic consistency, and its feeding into the enclosed space will be performed at one point of discharge from the transport pipeline. It should also be considered that the feed mixture will tend to slow the sedimentation of solid particles on the flow path in the excavation, and the excavation may also have a variable slope. A pictorial drawing of the liquidation of the dog heading excavation by backfilling it is shown in Figure 4.

In this drawing, we can see the space separated by two dams, one of which is full and without holes (the rear dam), while the other front dam has several inspection openings and two pipelines. The pipeline feeding the hydro-mixture, and the venting pipeline for the filled space, are also shown. The inspection openings are placed on the vertical axis every 0.5 m. They are designed to inform about the rising level of the hydro-mixture sediment while filling the free space of the excavation; they also allow for the drainage of excess water.

The hydro-mixtures intended for the liquidation of underground workings must meet a number of

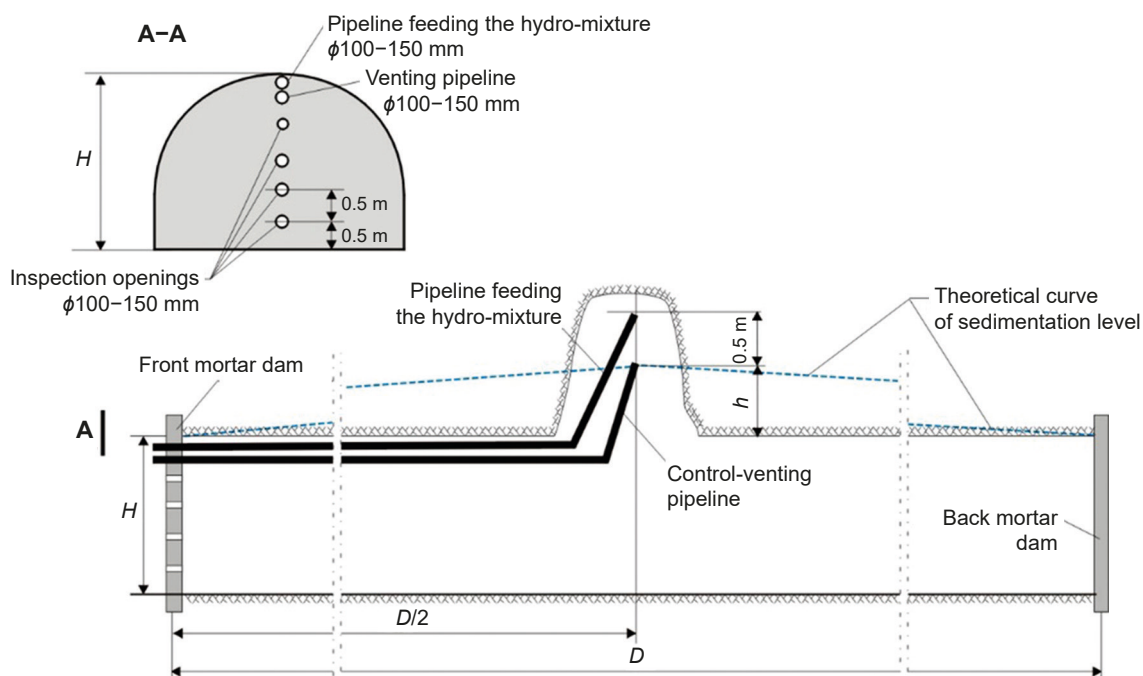


Figure 4. Diagram of the liquidation of a dog heading by a complete filling of the free space with a fine-fraction hydro-mixture

physical and mechanical criteria, in particular, the binding process and strength. To ensure the optimal course of the hydro-mixture binding process, and the strength parameters after its solidification, such hydro-mixtures are usually made of fly ash having binding properties with the possible participation of a binding agent, which is most often cement. From the point of view of the binding process and final strength parameters, the proportion of water in the mixture should be optimized in terms of the effectiveness of the hydration process and the chemical balance in the solidifying mixture. As the mixtures are delivered to their places of application, usually by hydraulic transport, the amount of water in the mixture is greater than that which results from the above-mentioned criteria, because it must take into account the parameters of hydraulic transport.

The optimization that involves the determination of the distance between the dams consists mainly of the assumption that, after considering the slope of the sediment surface (which can be determined at a laboratory stand), the working will be back-filled to the full height at the places where separating dams were placed. This assumption is possible in a horizontal working only in the case of feeding the hydro-mixture higher than the upper height of the working, as shown in Figure 4. In the central part of the liquidated space, it is necessary to extract some loose roof rocks, which makes it possible to raise the outlet of the pipeline supplying the hydro-mixture to a specific height h , and to ensure damming of the hydro-mixture. To guarantee that the adopted height h is attained, a venting and control pipeline is added. After the hydro-mixture reaches height h , the hydro-mixture will flow out through the control pipeline beyond the dam, which will indicate

that the assumed height has been reached. Table 3 presents examples of the optimal distances between the mortared dams, for a hydro-mixture prepared on the basis of fluidized ash of the consistency measured with the table spread equal to 160 mm, determined on the basis of the model slope tests of the hydro-mixture sediment.

Conclusions

Polish underground coal mines commonly use various fine-fraction energy wastes, which differ significantly in terms of their physical properties. These differences mean that the hydro-mixtures made with the same mass fractions of solids-to-water (e.g., 1:1) are characterized by significantly different physical properties, such as their table spreads, amount of excess water, unit energy losses of the flow, rheological parameters, or strength parameters. Considering the above, when undertaking any work involving the use of this type of hydro-mixtures, it is necessary to perform preliminary laboratory tests to determine its physical properties for a specific kind of energy waste. This fact is often forgotten in mines, and to ensure the so-called “safety” of pipeline operation of the transport installation, much larger amounts of water are added than would appear from the tests and requirements. This results in an increased share of excess water, which in turn has to be pumped out to the surface, in the leakage of the diluted hydro-mixture to the fracture zones of the rock mass and in the failure to achieve the required strength parameters.

This paper presents the results of research on the selected physical and mechanical properties of a solidifying hydro-mixture made on the basis of selected energy wastes in the form of ashes from a fluidized bed boiler. In the laboratory tests, hydro-mixtures made based on selected fluidized ash were used, with different mass fractions of the ash-to-water S/W, which resulted in the acquisition of various consistencies of the hydro-mixture and, consequently, different table spreads. This made it possible to show the influence of the water content in the hydro-mixture on the strength parameters, and a later estimation possibility for the consistency of the hydro-mixture introduced into the excavation, based on the obtained results of in-situ strength tests. For laboratory tests, the table test range of hydro-mixtures was assumed to be from 160 to 260 mm.

Based on the obtained results of the laboratory tests of the hydro-mixtures using the selected ash from the fluidized bed boiler, presented in point 2 of the paper, the following conclusions can be drawn:

Table 3. Example of the optimal distance between the dams D [m] with the backfilling and a hydro-mixture based on the extracted fluidized ash with a table spread of 160 mm, depending on the height of the excavation and the over-height difference h

Height of the working H [m]	Degree of overheight, h [m]					
	0.25	0.50	0.75	1.00	1.25	1.50
2.2	10.88	19.74	27.10	33.32	38.62	43.22
2.3	10.92	19.90	27.40	33.76	39.22	43.98
2.5	11.00	20.16	27.92	34.58	40.34	45.38
2.6	11.06	20.32	28.20	35.00	40.90	46.10
2.7	11.08	20.44	28.44	35.36	41.40	46.72
2.8	11.12	20.54	28.64	35.68	41.86	47.30
3.0	11.16	20.74	29.04	36.30	42.70	48.40
3.2	11.24	20.94	29.44	36.90	43.54	49.46

- with the increase in the proportion of water in the hydro-mixture, its density decreases. In the range of the table spread from 160 to 260 mm, the density was from 1452 to 1386 kg/m³, respectively;
- along with the increase in water content in the hydro-mixture, the amount of over-sludge water grows. In the table spread range from 160 to 260 mm, this amount was from 2.4 to 16.2%, respectively;
- with increased water content in the hydro-mixture, the uniaxial compression strength R_c decreases. As shown in Table 3, after 28 days of seasoning, the table spread ranged from 160 to 260 mm, the strength drops from 2.85 to 1.75 MPa and after 60 days from 3.52 to 2.58 MPa;
- all tested samples, after 60 days of seasoning in a climatic chamber and 24 h soaking in water, showed a loss of strength. The lowest soakability value of 7.7% was recorded for the hydro-mixture with a table spread of 160 mm, while the highest soakability of 25.2% was seen for a table spread of 260 mm.

Taking into account the technology of filling, using a cyclical gravity flow with the hydro-mixture acting down the workings, the obtained test results confirmed that the hydro-mixture should be characterized by higher table spread properties for increasing the migration range and attaining complete filling. It should be remembered that, with a table spread of 240 mm, the hydro-mixture has about 21.8% of over-sludge water (Table 3). Before introducing the hydro-mixture in the next cycle, this water should be pumped off or drained with the drainage pipes left behind. Otherwise, the water left in the excavation will combine with the new hydro-mixture and dilute it, resulting in a lower strength. In extreme cases, it is possible to feed fine-fraction hydro-mixture into the water while liquidating waterlogged workings or shafts. In such a case, comparative laboratory tests should be performed, which attempt to reproduce similar dosing and seasoning conditions of hydro-mixtures to confirm their suitability.

The research results presented in the paper enable us to conclude that the applied hydro-mixtures, based on fluidized ash, can be successfully recommended for all liquidation and filling works in underground workings. The undeniable advantage of these hydro-mixtures is the achievement of high

R_c strengths without the addition of binders, which makes them a substitute for the used mining binders in the strength class up to 3 MPa.

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Sustainability and Smart City

Hypothetical consequences of chemical contamination in the territory of the Municipality of the City of Szczecin during transport of hazardous materials

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JEL Classification: R130, R140, R480

Abstract

The modern security environment is marked with significant changes and unpredictability. This is true both for natural threats caused most often by forces of nature and for threats to civilization such as technical disasters or failures. The fact that these threats may be synergistic not only complicates efforts that are mainly intended to mitigate them but also makes it difficult to determine their direct cause. The article presents a hypothetical model of the spread of dangerous substances released during a disaster involving a tanker carrying 20,000 kg of anhydrous ammonia by road, by rail, and by water in the territory of the Municipality of the City of Szczecin. A 2016 rail disaster involving two derailed tankers carrying ammonia is proof of the likelihood of such an event. Great amounts of dangerous substances are transported through Szczecin's densely populated areas, most often to and from Zakłady Chemiczne Police S.A. (Police Chemical Plant), which causes a risk to the life and health of persons on the premises. The method of situation assessment in chemical, biological, and radiological contaminations (ATP 45 (Delta)) and the Promień IT system were used to forecast the hypothetical development of contamination. The results were compared with those of the ALOHA program. The author assumes that the conclusions from this paper will be used in the assessment of the likelihood of threat categories (KZ-3) and in the crisis response procedure (PRK-15), both included in the Municipal Crisis Management Plan.

Introduction. Normative and functional aspects

The changeability of today's environment of security, resulting mostly from civilizational changes, means that existing functional and operational solutions must be realized on an ongoing basis. The emerging threats are increasingly synergistic, which is an additional complication, especially at the stage of their neutralization.

Ensuring the efficiency of the national security system (security of the state) should be a key task

for all levels of public administration (central and local). The civic plan has been given a key role in this system. This plan is an integral component of crisis management (hereinafter CM), implemented at each level of the country's administrative division and by local and central authorities alike. In particular, it should result in the drafting of response procedures and in the determination of forces and measures adequate for removing threats that occur within the administrative boundaries of a given local government unit (LGU). The provisions of the Crisis Management Law (hereinafter CML) regulate

the subject matter of civic planning relatively precisely in the institutional, formal, and substantive spheres, and their ultimate goal is to prepare public administration for CM (Journal of Laws, 2020b). However, these provisions expressly emphasize that taking control over crisis situations, removing their consequences, and rebuilding of resources must be well thought-through and achieve purposeful moves forward. Therefore, there is no doubt that a thorough CM preparation should result from multidimensional actions, including the preparation of reliable planning documentation. CM plans (municipal, county, provincial, and national plans) are focused according to a uniform cycle specified in the statute (Article 3(7) CML).

This cycle provides for the following stages: analysis, programming, drafting of the plan or program, implementation, testing, and launching. The actions stipulated in these stages are conceptual, organizational, and executional and place special emphasis on the programming of relevant steps and their coordination and supervision during their implementation. At the same time, the planning process guarantees respect for the territorial or operational competence of the entities involved and the normative relations between them.

In preparation for a discussion of the said planning, the author used the findings included in the Municipal Crisis Management Plan (hereinafter MCMP) of the Municipality of the City of Szczecin (hereinafter Szczecin Municipality), the drafting of which is the responsibility of the Crisis Management and Civil Protection Department (BIP, 2021). The plan respects CM's essence and chronology: prevention, preparation, responding, removing consequences, and restoring resources and critical infrastructure (hereinafter CI). Apart from the planning, it also stipulates the improvement of existing solutions and the improvement of collaboration between the entities involved and the use of their resources, including warning, informing, monitoring, and alarming residents, rescue operations, medical and social assistance for their evacuation, training, and education. An in-depth analysis of likely threats and the real capacity to combat or prevent them is an integral part of the planning itself and updating it. The plan is periodically updated to take into account changes in baseline parameters and the experience from crisis incidents that have taken place in the territory of the Szczecin Municipality.

Due to the MCMP's volume, the author characterizes only its most important elements:

1. The master plan.

2. The set of actions to be taken in the event of a crisis situation.

3. Functional annexes.

The details of the plan are preceded by an introduction to the CM subject matter and a list of normative acts, internal management laws, and recommendations that provide the interpretation for the structure of its individual elements. The principal content of the master plan takes into account CM organization and general rules, characterization of threats with an assessment of their likelihood, identification of tasks and responsibilities of stakeholders involved, their relations and competences (security network), specific characteristics of forces and measures necessary to counteract threats and incidents, and the possible removal of their consequences. The characteristic features of the Szczecin Municipality and of the threats identified include an evaluation of their likelihood (risk and threat maps). Under a general typology, threats were systematized into two basic categories: the complex threats category (principal and related threats) and the cause-and-effect category (primary and secondary threats). The principal threats include those that require the concentration of the greatest number of response forces and measures, that decide whether the entity competent for their removal is the head executive officer of emergency response actions, and that may cause the greatest losses and damage. In turn, related threats accommodate those that run parallel to the major event, require the concentration of additional numbers of (usually a specialist) response forces and measures, that decide whether the entity competent for their removal supports the head executive officer of emergency response actions, and that may cause additional losses and damage. It is also assumed that primary threats are those that cause a dangerous situation, whereas secondary threats are dangers that emerge as a result of the activity of primary threats. When assessing the likelihood of threats, five categories are formulated: very rare (once every 500 or more years), rare (once every 100 years), possible (once every 20 years), likely (once every 5 years), and very likely (that happen once a year or more frequently). The five-level scale of threats (A to E) identifies potential consequences for life, health, and property and includes adverse effects (from negligent to disastrous). The plan also includes a list of abbreviations of parts of the world, meteorological data, risk level matrices, detailed descriptions of the 23 threat categories, and a register of potential causes of failures associated with the release of a dangerous chemical substance, which is crucial in verifying

the hypothesis of this paper. This part of the plan is presented as tables, which undoubtedly boosts its functionality. These tables include category name and code, threat type and description (general and detailed), classification of likelihood, consequences and risk, description of consequences of the threat, and of the capacity to respond.

Part two of the MCMP includes operational measures, that is 23 crisis response procedures (CRP). Here too, a table arrangement was used to present the catalog of threats. It is preceded by a specification of the type, place, scale, and consequences of events, the marking of dangerous zones, and a forecast of threat development as well as a description of responsibilities relating to monitoring and alarming residents. Moreover, the document describes the procedure for launching necessary forces and measures engaged in the implementation of planned actions at the moment a crisis situation occurs and names entities authorized to make decisions on the engagement of forces and measures.

Functional annexes are part three of the MCMP. They refer to an array of actions, the organization of which was included in the previously drafted CRP. They require a separate systematic description in the plan. They include full, updated database resources necessary in the performance of CM tasks. These annexes include:

1. Procedures for the performance of CM tasks, including those relating to the protection of CI and the launching of reserves, the organization of communications, threat monitoring, warning and alerting systems, evacuation, medical aid, social care, and social assistance, and the protection against threats characteristic to the city of Szczecin.
2. Rules for informing residents about threats and procedures in the event of such threats and procedures for documenting and assessing the damage.
3. Lists of contracts and agreements relating to the performance of tasks covered in the CM plan for CI in the territory of the city of Szczecin.
4. Priorities in CI protection and restoration.

Apart from these, the statute requires that CM plans – at the preparation stage – be agreed with the heads of organizational units (within their competence) who can be engaged in the implementation of the planned actions (Article 5(4–5) CML). Moreover, there is an obligation to ensure cohesion between CM plans and other relevant plans drawn up by competent public authorities, the drafting of which result from separate laws, as seen in Article 4(1)(6) CML that determines the compliance of CM

plans with plans drawn up pursuant to the Act of 22 August of 1997 on the protection of persons and property (Journal of Laws, 2020a).

The discussion on civic planning so far leads to the conclusion that for pragmatic reasons, the statute should also require that CM plans be coherent and take into account local and regional determinants. It is crucial that these plans are uniform at the regional level (within one province and its counties) and the local level (within each county and its municipalities) when it comes to monitoring threats, assessing forces, and the measures necessary in the event of a crisis situation and to the cooperation between these forces, warnings, and alarms, in particular informing residents about threats and related procedures, evacuation from vulnerable areas, and the organization of rescue operations, medical care, social assistance, and counseling (Guźniczak & Stempiński, 2021).

The methodological aspect

The article presents the projected development of a threat involving the release of ammonia compounds – UN 1005 (Messer, 2019) and chlorine compounds – UN 1017 (Messer, 2018) into the atmosphere. The author assumes that the exposition of these compounds into the atmosphere is a result of a technical failure following a transport disaster to or from one of the upper-tier establishments (Informacja, 2021) located 10 km north-west of the Center of Szczecin.

The method of situation assessment in chemical, biological, and radiological contaminations (ATP 45 (Delta)) and the Promień IT system (hereinafter PITS) are used to model the development of each of the incidents. Their application requires an authorization to use the Operational Graphics Package (Pakiet Grafiki Operacyjnej, hereinafter OGP) (Częścik, 2013). The OGP is a program that allows the imaging of the development of a tactical and operational situation during the planning and managing of operations of the armed forces relevant to the hazards identified (Paprotny, 2012). The system was originally designed for the needs of the Polish Armed Forces; however, for a dozen years or so it has also been used by the bodies of Poland's CM system to model the development of threats. The use of said programs and applications in this study was possible because the employees of the Szczecin Municipality made them available to the author.

The article's summary method of the analysis of the release of a Type-D chemical substance allowed

a prognosis of the development of the incident independently for three sub-types (from a stationary tank, from a moving tank, and in an unknown manner). The author used sub-type 2 of the method, that is the release of a substance from a moving tank (container) or from a container in motion, which in consequence causes the spread of contamination on large surfaces. By following rescue procedure rules – Emergency Response Guidebook (ERG) – and owing to the amount of the chemical in transportation (release amount), a large range of impact of the released substances was adopted. Using the method of a hypothetical case study analysis (Haramata & Witczak, 2018), the author assumed that

1. The incident occurs in June (air temperature of 24°C, permanent wind speed of 3 m/s NW, no precipitation).
2. The locations of substance release are 150 m to 400 m away from densely built-up and populated areas of the Szczecin Municipality.
3. The amount of the substance transported by road, rail, and water (river transport) is 20,000 dm³.

The effects of the release of the chemicals were pictured on maps generated by PITS. Permission to use this system for CM purposes was granted to CM teams at the level up to and including counties (Janowski, 2015). It needs to be emphasized here, however, PITS may be launched in a client-server structure and in a distributed computing environment.

The author used the ALOHA system to delineate threat zones and verify the forecasts for the spread of dangerous substances (Majder-Łopatka & Salamowicz, 2019). This program is used by the Szczecin Headquarters of the State Fire Service for ongoing analyses. This program allows a simulation of the consequences of toxic, flammable, or explosive substance emissions. Under such assumptions, it was possible to obtain the length of the range of the vulnerable zone and concentration limits for the life and health of persons within the emissions area. The values for high and very high concentrations (marked in figures by a red ellipsis or its segment) are as follows: 30–35 mg/m³ for ammonia and 2–3 mg/m³ for chlorine. These values greatly exceed the permissible threshold limit values (TVL, 14 mg/m³ for ammonia and 0.7 mg/m³ for chlorine) and short-term exposure limit (STEL, 28 mg/m³ for ammonia and 1.5 mg/m³ for chlorine), whereas minor ammonia and chlorine concentrations (marked in figures by a blue ellipsis or its segment) are within the permissible TVL and STEL. The TLV determines the value of exposure of an employee during an 8-hour, 24-hour, and average week work schedule that should not have adverse

effects on the employee's health during his working life, whereas the STEL means a value that should not cause adverse effects on the employee's health if it occurs in the workplace for up to 15 minutes and up to two times during a shift, with an interval not shorter than 1 hour (Journal of Laws, 2018).

In order to facilitate the comparison of contaminated areas, the author marked areas of major and minor contamination determined by the ALOHA system on a PITS-provided map.

On this basis, the author assumed that a substance release will pose a threat to persons present in the area of the Szczecin Municipality delineated by PITS and ALOHA. Where a hazard develops like this, it may provide a basis for ordering first-degree evacuation of persons outside this area. The author focused solely on the hypothetical determination of the area and number of persons at risk, and thus analyzed complex, multi-actor actions planned in the MCMP.

Hypothetical analysis of events

The City of Szczecin is located in the Szczecin Lowlands (approx. 60 km from the Baltic Sea and 30 km from the Szczecin Lagoon). The three micro-regions of the Szczecin Hills, that is the Warszewo Hills, Bezrzecze-Siadło Hills, and Bukowe Hills (highest hill – Bukowiec, 148.4 m above sea level), are the characteristic feature of the location of the city, which affects local wind conditions. Szczecin is administratively divided into four districts: Śródmieście (including Międzyodrze), Północ, Zachód, and Prawobrzeże. It borders Police County on the west, Gryfino County on the south, and Goleniów County and Stargard County on the east. The city's area is 301 km² (water bodies – 24%, forests and forest land – 16.9%, other utility areas – 51% (residential areas, industry, administration, etc.)). The population slightly exceeds 400,000 (211,000 women and 191,000 men). Szczecin's strategic importance as the node of the TENT network (rail, road, sea, river, and air transport) follows from its location at the crossing of transit routes that link Western Europe with Baltic Sea states and Scandinavia with the south of Europe.

One of the potential threats for Szczecin's residents involves the transport of hazardous materials through its center. In the first half of 2019, 214 tons of such materials, including anhydrous ammonia, methanol, butane, propane, fluorosilicic acid, and hydrochloric acid, were transported by rail transport alone. Additionally, the system of axle load sensors

operating in the Szczecin Municipality noted in 2017–2019 on average annually 31 million vehicles coming in or going out, including close to 80,000 vehicles that exceeded the maximum authorized capacity of 40 tons (ZDiTM Szczecin, 2021). The author assumed that approx. 25,000 of these vehicles are those that transport dangerous materials. It needs to be emphasized that Zakłady Chemiczne Police SA (hereinafter Police Chemical Plant) owns the Port of Police, which handles approx. 1.5 million tons of cargo transported by barges annually (Gucma & Juskiewicz, 2018).

Below, the author presents results of hypothetical simulations that delineate Szczecin's areas that are at risk of contamination with anhydrous ammonia and chlorine due to unsealing of tankers in road, rail, and water transport.

Release of ammonia and chlorine in road transport

The figures included in this chapter present a comparison of the development of threats of contamination with chemicals in the territory of the Szczecin Municipality using two programs: PITS (marked by a yellow triangle on all figures herein) and ALOHA (regions with major and minor contamination marked by red and blue ellipses, respectively). The first selected release location is at Szafera Street, *vis a vis* Netto Arena, which is on a road route to the Police Chemical Plant.

The first program (PITS) identifies the radius of the release zone and the radius of the threat zone (75 m and 4.6 km, respectively). This area covers 9.2 km², and close to 117,000 people may be present within its direct reach (10 neighborhoods: Arkońskie-Niemierzyn, Centrum, Łękno, Nowe Miasto, Pogodno, Śródmieście Północ, Śródmieście Zachód, Świerczewo, Turzyn, and Zawadzkiego-Klonowica). It needs to be emphasized that there are many

facilities in this area, such as three hospitals with a total bed count of 835 (Jakubiak, 2021), university campuses, educational institutions, social assistance facilities, sports facilities (a stadium and a sports hall), leisure facilities, public administration, trade and services facilities, a major part of the cemetery (largest in Poland, third largest in Europe), and residential buildings.

ALOHA forecasts outline two contamination areas determining the range of emissions, which is 3.8×0.3 km (area, 1.3 km²) for major contaminations (35 mg/m³) and 6×0.4 km (area, 2.4 km²) for minor contaminations (10 mg/m³). Thus, the vulnerable area is substantially narrowed covering only a part of 6 neighborhoods (major contamination) in which approx. 50,000 people may be present. The minor contamination area covers 8 neighborhoods (approx. 67,000 people). The emission zone does not cover any hospitals or other large buildings.

The hypothetical model of chlorine contamination using PITS demonstrates that in the event of its emission from a tanker, the radius or the release region is 600 m, whereas the threat zone extends for 16 km, that is 110.8 km², which is more than a third of the area of the Szczecin Municipality. The maximum vulnerable area covers parts of the city located on the left and right sides of the river (22 neighborhoods). It needs to be noticed that the potential contamination covers a key area of economic activity (harbor, fuel bases, three heat and power plants, a waste incineration plant, a food processing establishment, large shopping centers, and others) and transportation links strategic for the city. Also, recreational areas, including those that are valuable in terms of nature, are located in the vulnerable area, which multiplies the effect of the contamination, and the number of persons directly at risk is 210,000.

Modeling with the use of ALOHA demonstrates that the area of a major threat (3 mg/m³) spans across

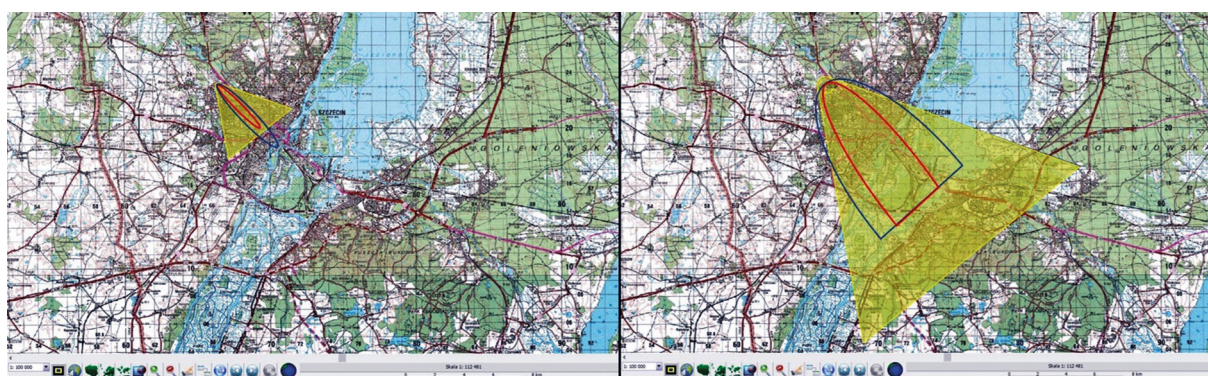


Figure 1. Maps of the area of the Szczecin Municipality contaminated with ammonia (the part of the city on the left side of the river) and with chlorine (the part of the city on the right side of the river) as the result of a road incident

38 km² (10×3.8 km). The potential area of a minor threat (1 mg/m³) has an area of 80 km² (10×8 km). It marks an area considerably smaller than what PITS forecasts, which is still more than 25% of the area of Szczecin, covering the strict center, including the business activity zone (all entities key to the maritime economy and the energy sector). In this case, the estimated number of those potentially at risk is close to 110,000 persons.

Release of ammonia and chlorine in rail transport

The next map shows the development of the threat of releasing ammonia in rail transport in the area of the Szczecin Municipality. The planned location of its release is on the overpass of rail route 406 situated above 26 Kwietnia St. The route links Szczecin and Trzebież and is used for cargo transport. The route also goes to and from the Police Chemical Plant.

PITS shows that the radius of the ammonia release region is 75 m, whereas the radius of the threat zone is 4.6 km. The maximum threat zone is 9.2 km². Approx. 92,000 people may be in direct danger (the area of 8 neighborhoods: Centrum, Międzydrze-Wyspa Pucka, Nowe Miasto, Pomorzany, Śródmieście Północ, Śródmieście Zachód, Stare Miasto, Turzyn). The area covers the strict center, which accommodates various facilities, such as health care facilities, university campuses, educational institutions, social assistance, sports, recreation, and leisure facilities (allotments), public administration facilities, trade and services facilities, residential buildings, and part of the largest cemetery in Szczecin. Moreover, the emissions area covers public transport centers (Szczecin Główny railway station, integrated tram and bus stops) and facilities strategic for the functioning of the city (Pomorzany sewage treatment plant and Pomorzany heat and power plant).

As in a road transport incident, ALOHA delineates two areas of contamination and determines their reach: 1.3 km² for major contaminations (35 mg/m³) and 2.4 km² for minor contaminations (10 mg/m³). The vulnerable areas cover only part of 7 neighborhoods (major and minor contamination) with approx. 60,000 residents. However, it needs to be noted that the maximum range of ammonia emissions projected in this way is about 6 km. Nevertheless, its area is much smaller than the area specified by PITS.

The chlorine contamination model determined by PITS demonstrates that in the event of emissions from a rail tank car, the radius of the release region is 600 m, and the vulnerability radius is 16 km. The maximum contamination area in this case covers 110.8 km². This is more than one-third of Szczecin's area, covering both the left and the right side of the river (20 neighborhoods with 185,000 residents). This covers an area of economic activity that is key to the city's development (harbor, fuel bases, three heat and power plants, a waste incineration plant, a food processing establishment, large shopping centers, and others) and strategic transportation links. This also applies to recreational areas, including those that are home to valuable nature. It needs to be emphasized that this multiplies the effect of the contamination, and the number of persons directly at risk must be updated to include those who are there temporarily (for work, school, medical treatment, official matters, shopping, etc.). Additionally, the modeling shows that areas of neighboring counties will also be partly at risk: Gryfino, Goleniów, and Stargard counties.

ALOHA shows that the zone with a major threat of chlorine contamination (3 mg/m³) has an area of 38 km², whereas the minor threat zone (1 mg/m³) has an area of 80 km². These areas, however, cover the strict city center, including the critical transportation

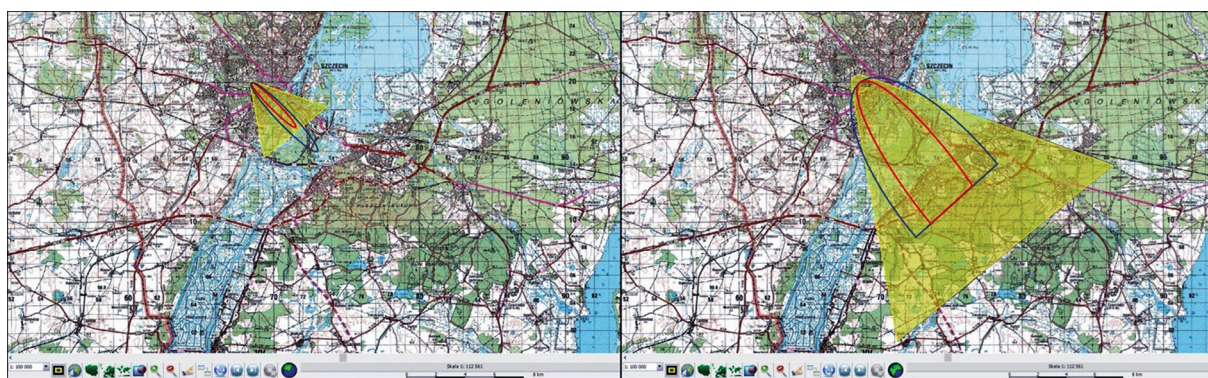


Figure 2. Maps of the area of the Szczecin Municipality contaminated with ammonia (the part of the city on the left side of the river) and with chlorine (the part of the city on the right side of the river) as the result of a rail incident

axis determined by national road 10 and railway route 351. There are no doubts that the risk involves the area of the harbor and industrial establishments located in its neighborhood (including those related to the maritime economy and the energy sector). The estimated number of persons potentially at risk is close to 165,000.

Release of ammonia and chlorine in water transport

The last incident in the analysis concerns emissions of ammonia and chlorine in water transport in the area of the Szczecin Municipality. The location of the release is situated in the West Oder flow, next to the Szczecin Harbor Administrative Office, 9 Jana z Kolna St. The author assumes that as in the previous cases, the incident is related to the transport of chemicals to and from the Police Chemical Plant. It needs to be emphasized that anhydrous ammonia is toxic and chlorine is very toxic to the water environment.

The PITS program analysis shows that the substance release region creates a circle with a 150 m radius, entirely within the water basin. The maximum area of the threat region is more than 9.2 km² (a triangle with 4.6-km sides). The direct risk covers partly or in whole the area of the following islands: Ostrów Grabowski, Ostrów Mieleński, Mieleńska Island, and Pucka Island. There may be approx. 5000 people at these locations, mainly employed in the territory of the harbor, in industrial establishments (including the industrial waste incineration facility and the Szczecin Heat and Power Plant), and in recreation and leisure places (water bodies and allotments). Moreover, the emissions area covers transportation arteries with intensive traffic.

ALOHA-assisted programming delineates and determines two contamination areas: 1.3 km² for

major contaminations (35 mg/m³) and 2.4 km² for minor contaminations (10 mg/m³). Despite the much weaker influence of ammonia, the area of major contamination covers part of the Dąbie Lake and harbor channels, whereas minor contamination affects marinas located in the south part of the small Dąbie Lake. This is particularly important in the summer season as then Szczecin's water bodies are used intensively by residents and tourists. The author assumes that about 3000 people will be at risk in this area.

The area of chlorine contamination determined by PITS demonstrates that in the event of emissions, the radius of the release region is 600 m, and the vulnerability radius is 16 km. The maximum contamination area covers 110.8 km². This area covers much of the Szczecin Municipality on the right side of the river, including strategic transportation links, large residential complexes, trade and service centers, logistics centers, food processing establishments, and recreational and sports areas. It also affects forest zones and water basins, which will undoubtedly have a negative effect on the condition of the natural environment (Gucma & Juszkievicz, 2018). More than 85,000 people may be present in this area of the Szczecin Municipality. Additionally, one needs to forecast the risk to persons in part of the Goleniów, Gryfino, and Stargard counties.

ALOHA delineates a much smaller area. The area of a major threat (3 mg/m³) covers 38 km², whereas the area of a minor threat (1 mg/m³) covers 80 km². This, however, causes a significant risk to intensive economic activity, the movement of persons by public and individual transport (rail, buses, and tramways), and the enjoyment of recreational areas. However, the potential threat to persons who live in large neighborhoods is the most significant. The estimated number of persons at risk is close to 63,000.

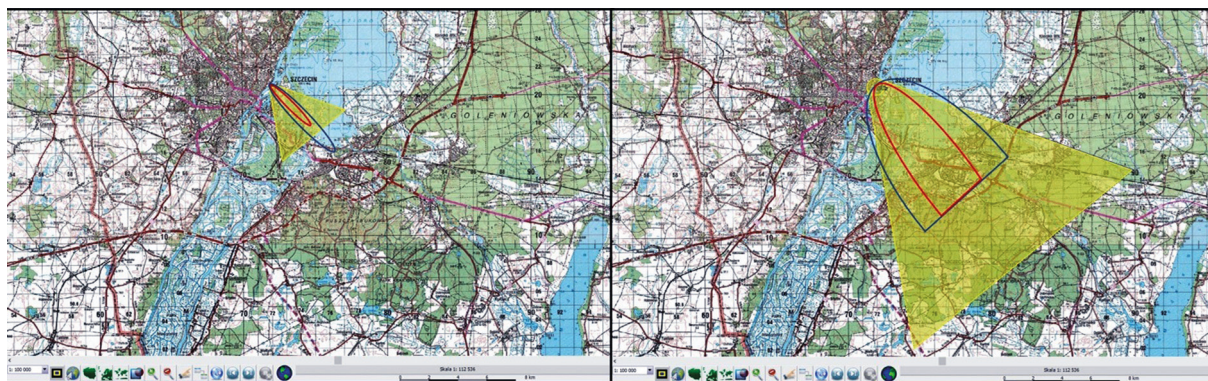


Figure 3. Maps of the area of the Szczecin Municipality contaminated with ammonia (the part of the city on the left side of the river) and with chlorine (the part of the city on the right side of the river) as the result of a water incident

Conclusions

The hypothetical development of contamination with two types of chemicals presented here (UN 1005 anhydrous ammonia and UN 1017 chlorine) in the territory of Szczecin encouraged the author to formulate the conclusions below.

1. There are significant differences between PITS and ALOHA when it comes to estimating the size of the area concerned and, thus, the number of persons at risk of contamination, in particular:
 - a) Modeling by means of the Promień IT system specifies only the size of the vulnerable area, whereas ALOHA identifies multiple parameters, including concentration limits and length/range of the vulnerable zone.
 - b) The PITS-proposed area of contamination with ammonia is 3 to 7 times larger than the area outlined by ALOHA; in the case of chlorine contamination, the differences in size between PITS and ALOHA estimates are 3.5- to 25-fold.
 - c) The number of persons at direct risk of contamination with ammonia according to PITS is 5000 to 17,000, whereas according to ALOHA it is 3000 to 60,000.
 - d) The number of persons at direct risk of contamination with chlorine according to PITS is 85,000 to 210,000, whereas according to ALOHA it is 63,000 to 165,000.
 - e) The greatest potential threat is contamination through the release of ammonia and chlorine during road and rail transport.
 - f) The greatest concurrence in estimating the number of people at risk of contamination calculated using PITS and ALOHA occurs in emissions of chlorine during rail and water transport.
 - g) The greatest discrepancy in estimating the number of people at risk of contamination calculated using PITS and ALOHA occurs in emissions of ammonia and chlorine during road transport.
2. Such great discrepancies in determining the area and the number of people concerned using PITS and ALOHA programs cause significant difficulties in taking the decision to evacuate the persons at risk. It may also have negative procedural consequences for the decision-makers.
3. An operational decision made by persons in charge of neutralizing these threats should be based on an ALOHA-aided analysis.

4. There is an urgent need to develop a uniform, compatible model of forecasting the development of contaminations for the military and the civil sector, which needs to take into account the most modern and diversified technological solutions. The changing environment of contemporary threats forces a step away from a departmental approach (i.e., separate for different entities) to identifying such hazards.

The forecasts presented in the article do not refer to MCMP structures intended to be launched in the event of the incidents described above. However, we need to note that effective (quick and understandable for the addressee) alarming of the people and their evacuation is a key issue in the event of contamination. The entire area of the Szczecin Municipality is within reach of alarm sirens launched remotely, complemented by a sound system allowing broadcasts of voice messages about different types of threats. This system undergoes regular ongoing upgrades. Moreover, for the need to order and carry out the evacuation of persons, more than 105,000 places in Citizen Support Centers (largely in educational institutions) have been prepared in the territory of the Szczecin Municipality. However, this number does not correlate with the hypothetical number of persons at risk, which is an additional argument to design and launch an application for optimal threat modeling.

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Smart and valued? ICT urban (transport) solutions in the city official communication

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Abstract

To optimize the everyday functioning of a city, urban authorities can implement smart city tools and solutions. Mobility is a typical field associated with the concept of a smart city. It is interesting to take a closer look at the solutions applied through the information accessible on the official websites, while exploring, at the same time, the possibilities offered by new research tools. The main objective of this work is to establish the significance of the information and communication technologies (ICT) in the process of creating smart mobility in a smart city, based on the texts posted on official websites. Using the natural language processing (NLP) methods and tools offered by the CLARIN.EU infrastructure, we verified dominant connotations with the mobility in the cities recognized as smart. The cities sample is the extract from the existing smart city rankings. To fulfil our goal, we searched for an answer to the question: What information about ICT solutions is posted on the websites of the studied cities and in what thematic contexts are they used? We looked for the results of the smart city rankings, referring to the official websites of the selected cities (a random selection from a total of 174 cities). The results show that mobility forms a distinct topic in smart cities communication, covering various kinds of transport solutions and systems, with a strong focus on the project side of this activity. The results are the part of the research “The smart city 4.0 maturity model,” conducted at the Department of Marketing and Logistics UO.

Introduction

The concept of a smart city was created as a response to the challenges of modern cities. Among others, this relates to the constantly growing number that populate cities, the urbanization processes, and the congestion. These phenomena cause enormous management problems and pose challenges for the transformation of urban life. The modernization of the cities' functioning methods entails the necessity to implement innovative solutions, based on digital technologies, and a cooperation between all

stakeholder groups. Thanks to new solutions supported by the information and communication technologies (ICT) tools, city planners and authorities strive to improve the functioning of the city in various areas, such as mobility, resources management, crime prevention, energy, health, and education.

The combination of the real and virtual worlds (Kagermann, 2014; Hermann, Pentek & Otto, 2016) results in the emergence of a new model of urbanization and smart city development. The technologies, such as big data, the internet of things, cloud computing, and cyber-physical system, clear the way

not only for the technological transformation of the city, but also for changing the lives of its inhabitants (Kupriyanovsky et al., 2016). Additionally, intelligent sensors and big data analysis enable real-time control. Thus, they support the smart city vision, which uses the most advanced ICT to provide value-added services for the city administration and its citizens (Zanella et al., 2014).

ICT transforms the smart city into an open innovation platform (Hernández-Muñoz et al., 2011), based on a ubiquitous network of sensors that meet the requirements of open, affiliated, and trusted platforms. In a smart city, economic growth is supported by information and communication technologies, which not only improve the city management, but also (and perhaps above all) stimulate social participation and the idea of sharing (Kitchin, 2015). In a smart city of this form, technologies serve people, providing them with comfort and safety, and improving the quality of life. However, it should be made clear that although technological solutions undoubtedly make life easier, when considered in isolation from the social context, they do not fulfil their role. With the above issues in mind, the aim of this article is to analyze the ways in which the cities can communicate, through their official websites, and the scope and areas of ICT application to their residents, which support not only the development of a smart city, but most of all the development of smart mobility.

Literature review – smart city in the context of the ICT solution

The concept of a ‘smart city’ is becoming increasingly more popular, which leads to different ways of defining it. An analysis of the literature enables a distinction between two main definitional trends: (1) a city functioning on the basis of the ICT technologies (Hollands 2008; Komninos, 2008) and (2) a new paradigm in the city development, in which the human and social capital, education, and the natural environment play a key role (Giffinger et al., 2007; Caragliu, Del Bo & Nijkamp, 2011; Lombardi et al. 2012; Neirotti et al., 2014). The technological trend of a smart city is reflected, *inter alia*, in the definition of Bakici, Almirall, and Wareham (2013), who perceive a “smart city as a high-tech intensive and advanced city that connects people, information and city elements using new technologies in order to create a sustainable, greener city, competitive and innovative commerce, and an increased life quality”. IBM defines a smart city in a similar way, i.e. “A city

is an interconnected system of systems. A dynamic work in progress, with progress as its watchword. A tripod [infrastructure, operations, people] that relies on strong support for and among each of its pillars, to become a smarter city for all” (Muller-Seit, Seiter & Wenz, 2016, p. 4). This definition indicates three key features of a smart city: (1) instrumentation, i.e. the presence of ICT solutions in the city (sensors and mobile devices); (2) connectivity, i.e. the availability of connections between the real and the virtual world by means of instrumentation; and (3) intelligence, meaning the ability to use new technologies in the process of the city development (Harrison et al., 2010).

The proponents of this approach claim that cities stand on the brink of a revolutionary breakthrough and will become dream cities. Every sphere of life will be digitized; applications, algorithms, and artificial intelligence will reduce congestion, prevent crime, and create free public services (Giffinger et al., 2007). However, will it really be so, or is the reconfiguration of the city to technological problems enough to make people feel good in the city? Probably not. Reconstructing the foundations of urban life, and managing the city from the technological perspective only, will lead to the cities being superficially intelligent and deeply full of injustice and inequality. Therefore, in the local government practice and in research discourse, the second trend of understanding the smart city is increasingly more often dominant, which transverse far beyond its technocratic perception. From this perspective, technological solutions only support the smart city, but thanks to them, it is easier to assemble information and a political vision into a coherent program for the improvement of the city and its services.

New technologies are an instrument for creating cities that are able to connect physical and social capital, provide improved services, and create infrastructure at a very high level of quality. This approach is reflected in the definitions of Caragliu, Del Bo, and Nijkamp (2011), who wrote the following: “We believe a city to be smart when investments in human and social capital and traditional (transport) and modern (ICT) communication infrastructure fuel sustainable economic growth and a high quality of life, with a wise management of natural resources, through participatory governance” This trend is also followed by Komninos (2008), who assumes smart cities to be the “territories with high capacity for learning and innovation, which is built-in the creativity of their population, their institutions of knowledge creation, and their digital infrastructure

for communication and knowledge management". A broader overview of the definition of a smart city has been described by Albino, Berardi, and Dangelico (Albino, Berardi & Dangelico, 2015).

A modern smart city is a concept that listens to the needs of its residents and naturally adapts to them. Technologies functioning in the city serve people by providing them with comfort and safety and increasing their quality of life. Nevertheless, as mentioned above, we know that technological solutions undoubtedly make life easier; however, when considered in isolation from the social context, they do not fulfil their role. That is why R. Robinson refers to the need for the mutual implementation of the vision of cities in the future, i.e. top-down, implemented by the authorities, and bottom-up, controlled by citizens (Robinson, 2015). If a city wants to be really smart, it must be a common space of stakeholders involved in developing ideas and creating innovations (Fritz et al., 2018).

In the context of modern information technologies, we can define a smart city as an "information technology combined with infrastructure, architecture, everyday objects, and even our bodies to address social, economic, and environmental problems" (Townsend, 2013, p. 15). A smart city is defined as a city in which ICT is merged with classic infrastructures, coordinated, and integrated using new digital technologies (Batty et al., 2012). Mitchell defines a smart city as an "intelligence based on the increasingly effective combination of digital telecommunication networks (the nerves), ubiquitously embedded intelligence (the brains), sensors and tags (the sensory organs), and software (the knowledge and cognitive competence)" (Mitchell, 2007). It does not exist in isolation from other urban systems or is linked to them only through human intermediaries. There is a growing network of overlapping connections ranging from mechanical and electrical systems installed in buildings to the systems embedded in household appliances, transport systems, electrical networks, plumbing, and urban security. Various definitions of a smart city indicate that the concept of a smart city is constantly evolving, which is a consequence of urbanization and digitization.

ICT technology, smart city, and mobility – relationships and dependencies

Creating a smart city based on ICT will solve various problems that cities experience. The largest influence of ICT on the execution of the smart city concept is in the area of smart mobility, which

means an enormous web of connections, transport, and communication, with a large speed that connects all the resources of the city (Stawasz, Sikora-Fernandez & Turała, 2012, p. 100). Smart mobility is narrowly connected with the implementation of ICT technologies and intelligent systems of transport (ITS). ICT technologies can be divided according to the level of its costs. In the first group, there are low-cost solutions related to the managing of applications that control the traffic lights of crossings and messages shown on boards with changeable data (VMS). In this group, there are also systems of automatic identification of vehicles (AVI). To solutions with higher costs, we place, for example, telematics that are a connection of countable technology (IT) with telecommunication. Its implementation in a macroscale allows, for instance (Kauf, 2019), the (1) increase in the safety of traffic and a lowering of the costs of external transport, (2) a reduction of pollution in the natural environment, and (3) a development of the intermodal transport. They also facilitate easier management of public transport – thanks to monitoring and controlling the fleet, improved access to information from users in real time, and the ability to plan a journey and create intelligent systems of transport (ITS). The main goal of which is to support, control, and manage the processes in transport as well as to connect these systems.

In a smart city, data platforms become the basis for a comprehensive digital transformation, which enables the identification and adaptation of solutions to specific problems of the city. They will facilitate partnership with the private sector as well as allow the residents to observe and value changes and, most importantly, be their co-creators. ICT enables the citizens, via their smartphones, to become mobile recipients of urban life and to take an active role in the life and creation of the city. The cloud technologies, and the development of wireless Internet, have become the basis for studying the flow of residents in specific transfer nodes, adapting traffic, and the intensity of public transport to the needs of residents, as well as automatic change of traffic lights. The residents of today's cities can use many services through their phones, such as public transport tickets, as well as submit comments on the functioning of the metropolis to its authorities. One of the examples is the Warsaw mobile application, through which citizens can inform municipal services about faults, neglected vegetation, or acts of vandalism. Intelligent transport systems improve the city traffic by providing drivers and authorities with information about the

current situation on communication routes. The city of Bucheon in Korea may serve as an example, where IBM has installed a camera system linked to the software that counts vehicles on the road. Thanks to them, the residents and city authorities were able to react faster and better to traffic jams. Equipping public transport stops, for instance, with an interactive information board and a Wi-Fi transmitter enables the collection of information about the number of people and the times with the highest traffic (Guanochanga et al., 2018). Equipping buses with beacons (small devices that send a radio signal and communicate with smartphones via Bluetooth connectors) and the combination of both 'digital traces', makes it possible to analyze the entire journey of travelers and to optimize the adjustment of the number of public transport vehicles to the actual needs. Equipping buses with ICT, measurably helps the travelers themselves, for example, through the Google Maps application, which checks train and bus timetables on an ongoing basis and informs about real-time changes (Lange, 2018). Therefore, when opening Maps, the exact time when the means of public transport appear at the stop can be seen.

The use of ICT in the mobility area connects the road users with the road infrastructure and information systems. Real-time information allows improved planning of the journey and facilitates the choice of the means of transport (especially in multimodal journeys), including more effective management of traffic. The basis for the development of intelligent transport systems are technological solutions, such as telematics. In a smart city, thoughtful and effective traffic management meets the needs of various groups of stakeholders who are the users of city infrastructure. Thus, the pursuit of intelligent mobility is not tantamount to the expansion of the transport infrastructure and building new lanes, but it means efficient use of space and creating real alternatives to individual transport. Such activities create an opportunity for a qualitative change, i.e. the improvement of the natural environment and living conditions in the city. Achieving satisfactory results in this area, and implementing the smart mobility idea, is a real challenge for the city as the authorities have to face the following problems:

- development and implementation of effective, sustainable, and safe public transport systems, including Mobility-as-a-Service solutions and other travel planning platforms;
- adapting to innovations in the field of mobility and acceptance of vehicles (i.e. electric, autonomous, shared, and communicating with each other);

- development of guidelines and strategies for meeting air quality standards, and maintaining them at the level specified by EU and national legislation;
- development of public-private partnership and cooperation with academic and research centers to solve the problems of environmental pollution, congestion, and sustainable development;
- construction of sustainable infrastructure (physical and digital) that support innovative mobility solutions offered by the public and private sectors.

Currently, there is probably no city in the world where the reality of urban mobility meets the needs and preferences of its residents while guaranteeing, at the same time, safe, clean, reliable, and cost-effective ways of traveling to your destination. Therefore, the key challenge of a smart city is to create such conditions for mobility that allows the reduction of congestion, road accidents and collisions, and, above all, reduce the negative impact on the natural environment.

In conclusion, the use of ICT allows improved management of mobility in the city and stimulates the inhabitants to cooperate. Smart city, based on ICT technology, i.e. integrating new technologies and innovative ideas, concepts, and solutions, requires cooperation and strategic partnerships. Only then will it be effective and efficient. It will guarantee improved quality-of-life for residents and enables the cities to cope with new challenges.

Research methodology

Optimizing the functioning of a smart city requires the use of appropriate ICT tools and solutions, whose task is to facilitate the movement within the city and reduce congestion. Therefore, an attempt has been made to analyze the applied and implemented ICT solutions on the basis of the available information on the official websites of the smart cities. The pilot study used thematic modeling tools to identify the main themes of the ICT-related communications offered by the cities. The research was carried out with the use of natural language processing methods and tools, which enabled a differentiation of the thematic groups concerning ICT in urban transport. To achieve our goal, we searched for an answer to the question: What information about ICT solutions is posted on the websites of the surveyed cities? We assumed that the thematic models (the topics) revealed in the study reflect the main uses of the ICT. The research procedure consisted of five stages, which are shown on Figure 1.

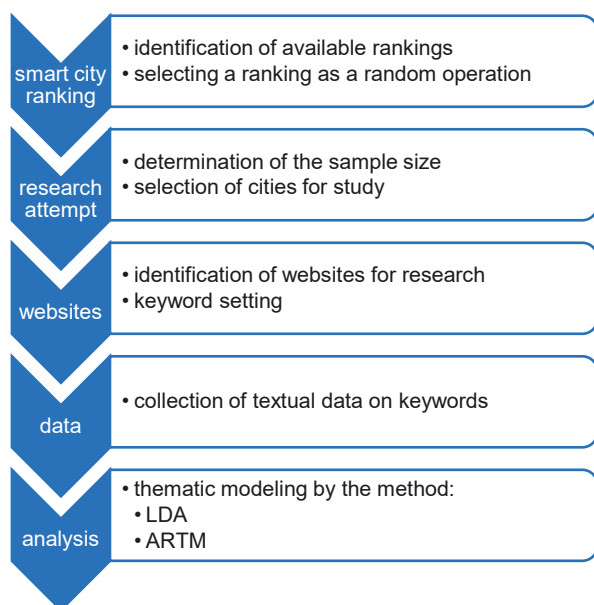


Figure 1. Schematic of the research procedure

Stage 1 consisted of the selection of city rankings, i.e. the smart city rankings were searched on the websites. There were 16 cities selected, in which the complete lists of the cities included in the ranking were available. The number of ranked smart cities ranged from 20 to 174, and the analyses were carried out at different time periods.

Stage 2 focused on the selection of the research sample. It was assumed that the most appropriate method would be to use representative methods. Thus, the size of the sample included the following: (1) internal differentiation of the general population features (variability of phenomena); (2) the applied sampling scheme, which largely determines the effectiveness of the study; (3) the adopted level of reliability of the results, i.e. the confidence level; (4) the method used to estimate the parameters characterizing the community; and (5) the available financial resources. It should be added that an increase in the sample size increases the precision of the estimator. However, the overall size of the sample does not depend on the size of the population, but on internal differentiation. Considering the above, the acceptable margin of statistical error was established at the level of 5% (for the confidence level $\alpha = 0.95$), while the population fraction equals 0.5 and the population size comprises 174 smart cities. The randomized survey was a list of 174 cities in the world, which were included in the IESE Cities in Motion Index prepared in 2019 (Berrone & Ricart, 2019). This ranking included the largest number of cities and was the newest available, in which a complete list of the analyzed cities was published. If the

sampling procedure was used, the necessary sample size was set at 120 cities. Nevertheless, due to the preliminary nature of the research, it was decided to study only a small number of cities, without keeping the minimum sample size. Out of 174 cities selected for this analysis, number 10 was adopted as the sampling interval using systematic selection, which enabled the selection of 17 cities, i.e. Tokyo, Los Angeles, Wellington, Gothenburg, Edinburgh, Lyon, Santiago, Seville, Moscow, Nottingham, Athens, Naples, Doha, Cordoba, Salvador, Novosibirsk, and New Delhi.

Stage 3 was dedicated to the selection of websites, i.e. the websites of the cities selected for the study were identified and the keywords were specified (*inter alia*, smart city, technology, and sustainable development). Stage 4 was the collection of text data. For the selected links, all of them returned by a Google search were collected, i.e. site X, "Y", where X is the website address and Y is the search term (quotation marks mean a direct hit to the content page). Such identified links, with matching text, were processed using Newspaper3k to download the content of the page. Using this method, a set of texts was obtained, which were analyzed through thematic modeling (Walkowiak & Gniewkowski, 2020), using the Multilingual Topic tool provided by the CLARIN.PL research infrastructure, via the web service portal (<http://ws.clarin-pl.eu/>). First, the clusters of non-randomly occurring words were distinguished by: (1) creating a model of the coexistence of words (giving information on how often certain words accompany each other throughout the body and in individual texts) and (2) calculating the probability of the occurrence of individual words in a random text extracted from the corpus. Then the words were linked in the so-called topics, i.e. the sets of words that coexist with each other. By means of statistical operations, such sets of words were distinguished, which probably do not coexist with each other by chance (the sum of the probabilities of occurrence must be 1).

Stage 5 concentrated on the text processing using the CLARIN infrastructure. The LDA and ARTM algorithms were used to extract topics. This enabled a definition of the thematic coherence, i.e. the content connections of the meanings of words that make up a single topic. The results are presented graphically. The size of the words in the graphic representation of the topic depends on the relative frequency of occurrence, i.e. the probability of the word occurrence in each document of the corpus.

Research result

The results were obtained for both methods, using LDA and ARTM algorithms to confront the reliability of the topics identified for predetermined keywords. As combinations, we used such keywords as “smart city”, “ICT”, sustainability, and technology. The final documents are accessible in various formats; for ease of interpretation, we chose distance mapping with clouds of words. Among 20 topics provided by both basic algorithms (LDA and ARTM), we selected those which contained the words referring to the mobility subject. For each analysis, the algorithms made 50 iterations on the blocks measuring 20 000 bytes (but respecting words length in each block). Each topic represents a distinct set of words from the texts that are included into the analyzed corpus. These topics – with statistical significance – denote different aspects of the subject described in analyzed texts. Part of the identified topics grouped words in other languages (i.e. Russian, Spanish, Italian, and Swedish) since the topic modeling tool operates in one language at a time. We chose English for the analysis as the most commonly used and accessible language, even on the websites of non-English speaking countries.

The initial data contained 4023 files in the txt format for almost all cities (except for Athens, for which any information with “smart city” notion existed in the moment of website scanning). Many of these files contained disclaimers, comments, lists of tabs, or links, so the necessary selection was reduced to 1498. Afterwards, they were grouped into thematic sets, containing 205 text files for the ICT theme, 196 for sustainability, 390 for smart, and 698 for technology. Not every city had a balanced set of texts; some keywords were lacking in the corpus, but the analysis produced a few interesting features (see Figure 2). The observations are ordered in two columns, respectively, for the algorithms used, i.e. on the left, the LDA modeling is shown, on the right – the ARTM. Words from the mobility field, such as “transport”, “vehicle”, “car”, or “traffic”, are weakly synchronized with ICT (images (a) and (b)), but the identified topic sets it together with the “city” and “project” notions.

It can be indicated that, in the analyzed corpus, the ICT used in the mobility field coupled with various projects executed or planned for the cities. The mobility vocabulary was more often present in the topics related to such notions as “smart”, “sustainability”, and “technology”. In the case of the “smart” topic, the mobility vocabulary coexists with the

system and city notions, which can be seen as confirmation of the perspective adopted in official communication offered by the authorities governing the analyzed cities. In the “technology” context, mobility is exposed as relating to the service (in LDA-led processing) or to the city project (in ARTM transformation results). In case of the “sustainability” topic, the mobility couples with residents (LDA version) or other stakeholders, such as students, experts, people, users, institutions, or conferences. Considering only the consistency of the word cloud that represent each topic, we can see that the LDA analysis provides a more coherent view of the aspects presented by the topic, while ARTM gives a less homogenous view of the themes present in the studied corpus.

Other interesting features of the identified topics are linked to the mobility vocabulary, e.g. more infrastructure-connected in the “smart” context or user-oriented in the “sustainability” milieu. Although the thematic sets were disjointed, as they regarded such keyword as “ICT”, “sustainability”, “technology”, and “smartness”, some lexical relationships endured in the majority of topics; for example, the terms “city – transport” arose when searching with keywords such as “ICT” and “sustainable development”. The words “city – project – system – transport”, however, were present in the topics for which the following keywords were used: “ICT” and “technology”. For each 30-word set, apart from the mobility vocabulary, we can identify some notions that are used to describe the same reality as the keywords searched in the texts, extracted from official websites.

Discussion

The results of the topic modeling used to extract the most relevant vocabulary from official information published on the websites of the smart cities seem to be promising in many ways. Thanks to the CLARIN-PL support, the search time and extraction of texts from various kinds of documents (printed materials, websites, audio materials, etc.) was shortened significantly. The methods used by CLARIN-PL allow for an exploration of the groups of co-occurring words, which describe the activities depicted in such texts by the frequency of their use in the analyzed documents. With a larger initial set, some hypotheses in the inductive research process can be sustained or denied. Our pilot research confirms that the used method is appropriate for the processing of large collections of texts and provides important results in the form of meaningful

Figure 2. Results obtained from selected smart cities websites that communicate the topic modeling method

topics that describe a given issue from different perspectives.

Even if the method used is statistically accurate, the problem of interpreting the results obtained is still a challenge. It requires an examination into the base body of the texts and carrying out a deeper analysis of their functions, their sender, and the recipients. An interesting case in this aspect is Moscow, whose official communication on the website largely focuses on the representatives of the city authorities and their activities. In contrast, the Gothenburg communication refers mainly to the events, without exposing the roles of the authorities. Even in such a limited form, our study signals the possibility to identify differences in the way information is formulated among the considered cities. In the collected texts, the thread of the initiating activities is strongly exposed, which is manifested by the word “project” present in most topics. The implemented solutions are accompanied by research (“study”, “survey”, and “respondents”) and they are systemic in nature.

It should be noted that environmental expressions are very poorly represented in the topics referring to mobility in smart cities. In the context of “technology” we can find “environment” and “emissions” (ARTM method), while in the case of “sustainability” we have “congestion” (LDA method) and “air” is denoted by both methods for the “smart” topic. Such a situation may result from a small sample size or by mainly associating the concept of a smart city with technological advancement, omitting the environmental effects. In addition, it should be emphasized that the cities used for this study represent the entire cross-section of rankings, i.e. from those that occupy the highest places to those placed in the last positions. This surely has an impact on the outcome of the study, as the cities included in it represent a diverse level of awareness and needs, resources and capabilities of action, and the sophistication of the implemented solutions. The results of our study indicate that the ICT solutions are poorly linked to mobility in the selected cities. By contrast, in the technology-related topics, the mobility concepts are clearly represented. The absence of solutions from the known literature, mentioned in item 3, may be puzzling. It seems that, on the one hand, this is influenced by the specificity of websites with information addressed to residents and, therefore, given without or with simplified specialized vocabulary. On the other hand, the variety of available solutions results in a lower frequency of occurrence of their names and, consequently, less visibility for the search algorithm.

In this context, it is noteworthy that the dominant technological solution used in the studied smart cities are cameras, clearly present in the “technology” and “smart” topics. Then again, in the “smart” topics, the concepts related to the transmission of information (“hotspot”, “portal”, “signal”, and “screen”) and means of transport (“train”, “bus”, “car”, and “metro”) with its basic infrastructure are mentioned. It is interesting that most expressions relating to the smart city stakeholders appear in the context of sustainability (“expert”, “student”, “user”, “pedestrian”, “resident”, “family”, and “institution”). This situation may result from an account of the social aspect in the dimension of sustainability to a greater extent than in other contexts (technology, either ICT or smart). However, the absence of concepts related to ecology is puzzling. Is this dimension of sustainability so obvious that it is not mentioned on the websites of smart cities? In order to interpret the obtained results to a high standard, it is necessary to examine the websites of the studied cities and verify the other research questions that were formulated in the process of our analysis. This will be the next step in our research, which is beyond the scope of this study. The pilot studies conducted so far shows that the applied thematic modeling procedure is a useful tool at the initial stage of research, which contribute significantly to the construction of a set of research questions that make a multifaceted analysis of the studied phenomenon possible.

Conclusions

The relatively limited number of cities covered by this study, during the pilot study, enabled the formulation of careful conclusions only. We note the usefulness of the method employed to explore large sets of text data and to extract statistically significant topics from them. However, their preparation is time-consuming and their interpretation cannot be undertaken without a reference to the original texts. In light of the conducted research, we can conclude that in the analyzed sample of cities and texts, the connection between the concept of a smart city, broadly understood mobility, and ICT technologies was confirmed. Still, the aspect of environmental friendliness is poorly represented. Even if the selected cities have sustainable development strategies, this thread in the acquired texts is hardly visible.

The obtained results confirmed that smart cities are based on new information technologies, which they communicate to residents on their official websites. However, these technologies are not always

associated with mobility and transport. This may be due to the fact that the information was obtained from the official websites of cities, and not from public transport entities for which the use of ICT seems obvious. Nevertheless, the obtained research results should send a signal to the city authorities that the information provided through official channels (i.e. websites) on the scope of the ICT implementation for mobility is insufficient. Therefore, the city residents may not have adequate knowledge about the smart mobility development. This conclusion creates further directions for future research exploration, which may allow the identification of the scope of the ICT usage in smart mobility. One of them may be an analysis on the residents' opinions expressed in social media or in comments posted on official websites. The information obtained by this method could, for example, be the basis for the evaluation of smart mobility implementations, and possible corrections that enable an improved response to the needs of residents that encourages them to use public communication more often.

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Is sustainable aligning with smartness in transport domain? – marketing perspective of smart city rankings

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Abstract

Rising awareness of sustainable development challenges, along with the quest for optimization of the everyday functioning of the city, motivate many urban authorities to search for promising concepts and solutions. One of these is the smart city concept, which has gained governors of cities' attention for little more than ten years. An object of research and development, it is still a distinctive feature for the cities that adopt this concept. City marketers use such distinction towards a large palette of beneficiaries of the city. At the same time, it deploys some traits suggesting synergies between the implementation of smart city solutions and sustainable development goals.

The main objective of our work was to verify if the relationship between these aspects (smartness and sustainability of a transportation) in smart city rankings exists and, if that is true, what impact it has on marketing communication of the city comprised in such rankings. To fulfill this goal, we answered such research questions as: what place sustainability criteria in smart city rankings have occurred, how is the transport represented in these criteria, what use graded cities make of their presence in such competition, and which perspective dominates (if any) in daily marketing communication activities of the city.

To provide such an analysis, we considered the criteria used to rank the cities to find the places that accorded to sustainable ones. We examined the marketing use of the results of such rankings, referring to the official websites and social media of selected cities (random selection from the total population of 174 cities comprised). The sources used to provide the data in natural language, and their analysis proceeded with methods and tools used in NLP (natural language processing), which are accessible through CLARIN.EU infrastructure. The results determine that cities can be classed into different groups, accordingly to their sustainability/smartness pending, and ability to use accorded ranks in marketing context.

Introduction

Since the dawn of time, society has been striving to improve the conditions of people's life. Therefore, the city as one of the main forms of human functioning is constantly changing. The vision of the city of the future is a smart one, in which information and

communication technology (ICT) supports sustainability thanks to modern technologies (Ahvenniemi et al., 2017). The urban center of the future should be safe, secure, environmentally green, and efficient because all structures – whether for power, water, transportation, etc. that is designed, constructed, and maintained with advanced, integrated materials,

sensors, electronics, and networks – all interfaced with computerized systems encompassing databases, tracking, and decision-making algorithms (Hall et al., 2000). To solve a wide range of problems, such as congestion and security, city authorities implement distributed sensor networks, video surveillance, and predictive analytics. Modern technology contributes to the optimization of processes occurring in the city, and it is crucial to increase the quality of life of its inhabitants. Freedom of movement within and outside the city is an important criterion for the quality of life, which is ensured by the transport function of the city, with consequences such as urban sprawl (Riera Pérez & Rey, 2013) or strong incentives (sometimes even economic pressure) toward public transportation use (Zabel & Kwon, 2021).

The smart city concept, reflecting the wishes of stakeholders, aims to create a space where ICT will support city management. One goal of smart cities is to systematically collect and analyze data on all city flows and services, from traffic patterns to utility usage, in order to improve efficiencies and reduce costs (Monahan, 2018). At the same time, smartness may not hinder the sustainability understood as economic, social, and environmental objectives achievement, in a way that should not limit the development opportunities of future generations. The synergy between the sustainable development goals and the implementation of smart city solutions was recently studied by Ahveniemä et al. (Ahveniemä et al., 2017). Their meticulous work revealed the similarities between smartness and sustainability of a city in the rankings, which addresses these aspects. In the present work, we concentrate on cities classified as smart to verify how the concepts of sustainability and mobility (transportation) shape their daily communication through their official sites. Then we discuss the marketing potential of smart city rankings and the extent in which the examined cities benefit from it. The paper addresses the following research questions:

RQ1: How does the ongoing communication of a city (classified as smart) address the issues of sustainability and transport?

RQ2: Do the graded cities use the marketing potential of their presence in SC ranking?

The first part of this paper contains a literature review on two central issues. The first examines the smart sustainable city concept and features, to expose the part that accords to transportation among assessment criteria of city rankings. The second considers the city marketing framework and its potential to support smart sustainable urban development. Next,

the research method is presented and, subsequently, the outcomes are obtained. The article ends with a discussion of the research results and a conclusion.

Literature Review – sustainability & smartness of the city

Towards smart and sustainable city

The concept of a sustainable and smart city was crystallized during the 1990s. A sustainable city (United Nations Sustainable Cities Programme) is supposed to develop by fulfilling the demand of respecting the environment while ensuring “equality of income, employment, shelter, basic services, social infrastructure, and transport in urban areas” (Hiremath et al., 2013). The development of cities, for which their authorities (e.g., local governments) are responsible, should also take into account inter-generational equity (Maclaren, 1996), as well as the inclusion of residents and other stakeholders in co-determining the directions of this development (Mueller et al., 2018; Mangnus et al., 2022). Among the postulates and solutions supporting sustainable urban development, one can point to the idea of the “compact city” (Jenks, Burton & Williams, 1996), the “shared city” (Cohen & Muñoz, 2016), or the “changing city” (Wolfram, 2016), whose characteristics are presented in Table 1.

The term smart city was first used in the 1990s to describe the importance of new information and communication technologies in relation to modern infrastructure in cities (Albino, Berardi & Dangelico, 2015). The diversity of ICT applications in supporting urban development results in multiple definitions of the smart city (Maček, Ovin & Starc-Peceny, 2019). They derive from knowledge-based creative strategies that aim to improve the socio-economic, environmental, logistical, and competitive performance of cities and harness human, infrastructural, social, and entrepreneurial capital (Kourtit & Nijkamp, 2012). A smart city is an efficient, technologically advanced, green, and inclusive city (Vanolo, 2014). In the smart city concept, we can find six main areas such as smart economy, smart mobility, smart environment, smart people, smart living, and smart governance (Albino, Berardi & Dangelico, 2015). As Korzeniowska (Korzeniowska, 2018) noted, this concept is often narrowed down to a vision focused on the integration of the physical and virtual space of the city, instead of deepening the relationship between technology and the ability to interpret data and find solutions.

Table 1. Characteristics of concepts supporting sustainable urban development (own compilation based on (Jenks et al., 1996; Cohen & Muñoz, 2016; Wolfram, 2016))

Author	City concept	Features and descriptors of the city concept
Jenks et al. (1996)	Compact city	Increase housing density, provide a mix of uses, reduce urban sprawl, and achieve social and economic diversity and vitality.
Cohen & Munoz (2016)	Shared city	Categories subject to sharing in the city and their forms: energy (energy cooperatives and group purchasing), food (joint food production, sharing of manufactured, and processed food), goods (3D printing, leasing of goods, service assistance, and libraries), mobility and transport (forms of transport), and space (places to work and stay).
Wolfram (2016)	Changing city	Components of city transformation potential: inclusive and multiform urban governance, transformative leadership, empowered communities of practice (CoP), system(s) awareness, sustainability foresight, CoP experiments, innovation embedding, reflexivity and social learning, working across human agency levels, and working across political-administrative levels and geographical scales.

Galdon-Clavell (Galdon-Clavell, 2018), while analyzing ICTs in the city and pushing for the implementation of modern technologies in every sphere of life, points to overlooked issues related to the legal, social, and ethical impact of smart environments and technological solutions introduced in a seemingly uncritical manner. This means that society may perceive smart city elements as an excessive intrusion into private life and even the tracking of people by ICT companies. Marsal-Llacuna and Segal (Marsal-Llacuna & Segal, 2016), on the other hand, pointed out the omission of social aspects of the smart city in the scientific literature, in favor of the development of IT concepts to create new tools to further improve environmental and economic efficiency. Similarly, Adamczyk et al. (Adamczyk et al., 2019) highlighted the significant divergence between technological and social rationality, while pointing out that technological development supports the formation of a new social order in which “a sustainable future is becoming the universal common good and ideology of the inhabitants of a digital world”.

The similarities between the two concepts have led many researchers to search for the rationale and manifestations of this parallelism. Estevez et al. (Estevez, Lopes & Janowski, 2016), analyzing 876 scientific publications on smart cities, drew attention to the sustainability that goes hand-in-hand with the smart city. Also, Treude’s (Treude, 2021) review of scientific papers from 1997 to 2020 indicated a remarkable closeness between the definitions of a smart city and a sustainable city. Toli and Murtagh (Toli & Murtagh, 2020) reviewed the definitions of a smart city, which draws attention to the sustainability orientation present in them. They pointed out that some smart city definitions combine soft capital, such as human and social capital, and hard capital, i.e., the physical infrastructure of a city, to provide a sustainable, livable, and efficient city.

The linking of smart city elements also takes place in the form of an electronic communication network developed by the inhabitants, which substitutes its nervous system and determines the ‘intelligence’ of the whole system (Maček, Ovin & Starc-Peceny, 2019). Bibri and Krogstie (Bibri & Krogstie, 2019), propose a model for a smart sustainable city that stresses the need for its technological and ecological sophistication. They also pointed out that this model requires adaptation of technological systems for the practice of city functioning, otherwise in one city the implemented technologies will be accepted and in another rejected. According to Dhingra and Chattopadhyay (Dhingra & Chattopadhyay, 2016), there are four attributes of smart and sustainable cities, among which are sustainability, quality of life, urban aspects, and intelligence. In contrast, Höjer and Wangel (Höjer & Wangel, 2015) described a smart sustainable city as one that:

- meets the needs of its present inhabitants,
- does not compromise the ability of other people or future generations to meet their needs and, thus, will not exceed local or planetary environmental limitations, and
- is fully supported by ICT.

Both the sustainable and the smart city are becoming objects of observation for extensive monitoring systems that facilitate their management. The monitoring of urban sustainability started in the 1990s with various indicators. Urban sustainability indicators support stakeholders to take appropriate actions. Indicators should contribute to an improved comparison, assessment, and forecasting of processes in individual cities. Among the tools for measuring urban sustainability are BREEM, LEED, Green Star, and CASBEE (Reed et al., 2009). Published rankings of sustainable cities can be used for benchmarking and further strategy development by city authorities. Work on measurement systems has both

Table 2. Distribution of smart city and urban sustainability indicators among sectors and impact categories (Ahvenniemi, 2017)

Impact categories	Framework type: A – smart city; B – urban sustainability	Sectors										Total
		Natural environment	Built environment	Water and waste management	Transport	Energy	Economy	Education, culture, science, and innovation	Well-being, health and safety	Governance and citizen engagement	ICT	
Environmental sustainability	A	5%	1%	7%	4%	2%	0%	0%	0%	0%	1%	20%
	B	11%	5%	10%	7%	5%	1%	0%	0%	2%	0%	43%
Economic sustainability	A	0%	1%	0%	1%	0%	15%	5%	0%	2%	3%	28%
	B	0%	1%	0%	0%	0%	5%	1%	0%	1%	0%	10%
Social sustainability	A	3%	2%	1%	2%	0%	4%	11%	15%	8%	7%	52%
	B	5%	7%	3%	4%	1%	3%	3%	15%	5%	1%	47%

an academic and a commercial character. The comparison of indicators from methodologies (frameworks) for measuring smart and sustainable cities by Ahvenniemi et al. (Ahvenniemi et al., 2017) confirmed that both concepts describe the same reality. This is evidenced by the comparison of indicators (958 in total) included in both types of frameworks that assess cities according to their smartness and sustainability (Table 2).

The work of Ahvenniemi et al. (Ahvenniemi et al., 2017) justifies treating both dimensions of the modern city concept (smart and sustainable) as substantially similar. This seems acceptable, as these authors have documented the fact that both smart city models and sustainable city models have similar indicators, with similar sectoral and categorical distributions. What is important in this comparison is the co-occurrence of mobility-related criteria in both types of measurement methodologies and in all the impact categories. This means that the transport dimension is important for both sustainable and smart city objectives and supports their development in environmental, economic, and social terms.

City marketing concept and features

The application of the concept of marketing in the activities of cities can be dated back to the 1980s, to the practice of promotional activities of cities in Denmark (Braun, 2008) and England (Kavaratzis & Ashworth, 2005) and, since the 1990s, the first texts on this subject have begun to appear (Gertner, 2011) justifying the treatment of spatial units (city, region, community, and country) as an object of marketing activities within location marketing. The rationale for its emergence was the competition between cities and their regeneration efforts, for both of which the

city image became a tool (Braun, 2008). The successive phases of the evolution of awareness and marketing activities of cities or locations have been the subject of many studies (Braun, 2008; Kavaratzis, 2008; Lucarelli & Olof Berg, 2011; Gertner, 2011; Osorio-Andrade, Murcia-Zorrilla & Arango-Espinal, 2021), which indicates a diversity of approaches and perspectives to these issues. Gertner (Gertner, 2011) concluded from 211 texts on this topic (location marketing) that, until 2009, research in this area was in the first stage of the theory-building process (descriptive, not normative stage). The review conducted by Osorio-Andrade et al. (Osorio-Andrade, Murcia-Zorrilla & Arango-Espinal, 2021) of 295 texts on city marketing from 2003 to 2015, from the Web of Science resources, did not attain any new information in this regard, because the authors focused on bibliometric analysis.

According to Braun (Braun, 2008) “city marketing is the coordinated use of marketing tools supported by a shared customer-oriented philosophy, for creating, communicating, delivering, and exchanging urban offerings that have value for the city’s customers and the city’s community at large.” For place/city marketing, it is important to plan its development (Metaxas, Juarez & Gaby, 2021), which involves meeting the needs of residents and businesses (constant users) and tourists (occasional users), increasing the attractiveness for potential target markets (Metaxas, 2006), through tailored offers, i.e., for residents (Lee & Lee, 2014) or tourists (Liu, Yu & Liu, 2015). Place/city marketing activities were initially narrowed down to promotion, gradually becoming part of strategy planning for cities – especially their brand (Braun, 2008; Eshuis et al., 2018), namely, by responsible city authorities seeking to achieve competitive advantage (Moilanen, 2015). A distinctive

brand supports the city's decision-making processes (i.e., spatial planning and leisure activities) (Eshuis et al., 2018). It is an important locational factor in the context of global competition – it identifies and distinguishes a city from others, attracting residents and visitors (Kaufmann & Arnold, 2018), but its definition is fraught with challenges.

Moilanen (Moilanen, 2015) included: large number of stakeholders; limited understanding of branding among key stakeholders; limited internal buy-in among stakeholders; difficulties in securing sufficient funding; general slowness and time-related challenges; organizational issues and lack of authority to lead; operational level challenges in marketing communication campaigns and in transferring the brand identity to product experiences; and, finally, weak situational awareness resulting from poor monitoring. Different stakeholders perceive the city differently (Merrilees, Miller & Herington, 2012; Braun, Kavaratzis & Zenker, 2013), which complicates the development of its brand and, at the same time, opens the opportunity to understand the needs of target groups (Maček, Ovin & Starc-Peceny, 2019) and adapt marketing activities to them (Kavaratzis & Ashworth, 2005). In terms of target groups, tools for measuring the effectiveness of city marketing are also proposed, taking into account their economic dimension (Goovaerts, Van Biesbroeck & Van Tilt, 2014).

From the beginning, the development of the concept of place/city marketing was accompanied by criticism directed at the successively identified limitations of the dominant approaches of the time. Initially, this criticism was directed at the commodification of the city caused by the application of the marketing concept to the complex reality of the city. As the concept crystallized, it drew attention to the risk of focusing on selected target groups, which can have side effects on other members of the city community (Braun, 2008). In the same direction is a more contemporary critique of city branding, whose main axis is the inclusion of citizens in the branding process and its democratization (Vanolo,

2018) or the broadening of its spectrum to include aesthetics and ethics (Lucarelli & Olof Berg, 2011). In a similar vein, Kavaratzis (Kavaratzis, 2009) commented on the discrepancy between the theory and practice of city marketing. In this study, the aim of marketing activities, by involving as many stakeholders as possible in the design of the activities, is also the rationale for the pilot study of tools that could achieve this effect on the basis of textual data.

Research Methodology

Involvement in activities that result in the inclusion of smart cities in the rankings is an expensive challenge for cities. Discounting the expenditures incurred for this purpose should include all activities – including the marketing use of the “smart city” label. This allows the building of a coherent image of the city. However, the advantage of appearing in the smart city rankings is not always used. In order to determine the situation in this respect, we planned a study with the use of methods and tools for natural language processing available through the CLARIN infrastructure (<https://clarin-pl.eu/index.php/en/home/>). For the cities drawn from the smart city rankings, these tools enabled the identification of how the concept of transport occurs in the context of the messages posted on the official websites of cities. The next step was to determine whether the cities from the smart city rankings use this label in their communication with the environment. The research results presented in the paper are part of the research project entitled “Smart City Maturity Model 4.0”, which started in 2020 at the Department of Logistics and Marketing of the University of Opole by Anna Bruska, Nataliia Boichuk, Sabina Kauf, and Iwona Pisz.

The research procedure consisted of five phases (Figure 1): (1) selection of city rankings, (2) selection of research sample, (3) selection of websites, (4) collection of text data, and (5) text processing using the CLARIN infrastructure tools.

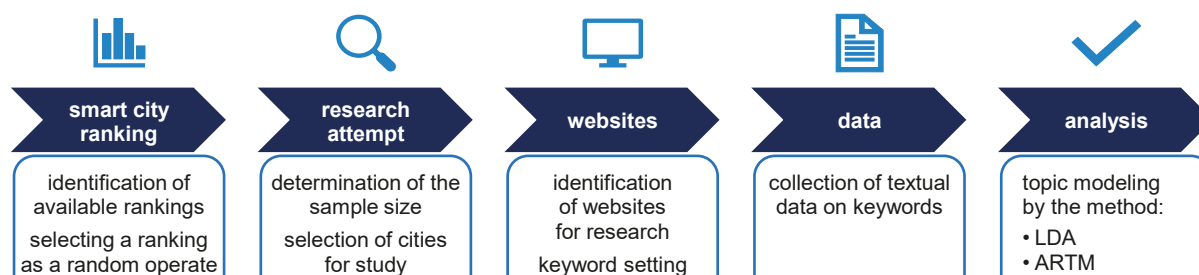


Figure 1. The research framework

We used the smart city rankings available on the web. From the gathered set, 16 were chosen, in which complete lists of cities included in the ranking were accessible. In 16 selected rankings, the number of classified smart cities ranged from 20 to 174, and the analyses were carried out in different time periods. We compared the cities nominated for those rankings to find the most exhaustive possible, and the final choice of reference classification fell on the list of 174 cities in the world, included in the IESE Cities in Motion Index ranking, prepared in 2019 (Berrone & Ricart, 2019). This ranking covered the largest number of cities and was the latest of the available ones, in which a complete list of analyzed cities was published.

Due to the pilot nature of the study, the number of cities included in the sample was limited without maintaining its minimum size. Using a representative method, the sample size is determined by (1) internal variation of the characteristics of the general population (variability of phenomena), (2) applied drawing scheme determining to a significant extent the effectiveness of the study, (3) the assumed level of reliability of the results – the level of confidence, (4) the method used to estimate the parameters characterizing the community, and (5) the available financial resources. It should be added that the increase in the sample size increases the precision of the estimator, but the overall sample size does not depend on the size of the population but on internal differentiation. With this in mind, the permissible margin of statistical error was set at 5% for confidence level, $\alpha = 0.95$, a population fraction equal to 0.5, and a population size of 174 smart cities. If the drawing procedure was used the necessary sample size would be set at 120 cities. Of the 174 cities selected for analysis, using systematic selection, the number 10 was taken as the interval of the draw, which allowed the selection of 17 cities, such as: Tokyo, Los Angeles, Wellington, Gothenburg, Edinburgh, Lyon, Santiago, Seville, Moscow, Nottingham, Athens, Naples, Doha, Cordoba, Salvador, Novosibirsk, and New Delhi.

In the next step, we identified the websites of the drawn 17 cities, to gather the data and defined keywords on these websites from the texts relevant to our study (e.g., smart city, technology, and sustainable development). We send the selected links to the CLARIN support team, and they collected for us all the links that the Google browser returned. The links were presented in the following form: site “X” and “Y”, where X is the address of the page and Y is the search term. Here, inverted commas indicate a direct hit on the page content. The links identified in this

way, i.e., with texts that meet the criteria, have been processed using newspapers to download the content of the page (see Table 3).

Table 3. Initial text distributions

Smart City	Smart City rank	Initial texts	ICT texts	SD texts	Smart texts	Tech texts
Athens	106	0	0	0	0	0
Cordoba	136	140	0	5	8	1
Delhi	166	134	5	3	3	16
Edinburgh	46	220	19	12	9	40
Lyon en	56	335	0	29	8	21
Lyon fr	56	316	0	11	0	35
Goteborg	36	232	9	2	5	11
Los Angeles	16	345	1	52	47	63
Moscow	86	770	83	30	153	216
Naples	116	311	22	10	20	39
Nottingham	96	168	14	13	6	26
Novo Sybirsk	156	50	0	0	5	3
San Salvador	146	133	3	6	3	11
Santiago	27	5	0	0	3	3
Sevilla	76	92	0	0	47	30
Tokyo	6	400	46	22	69	96
Wellington	26	372	3	1	4	87
Total		4023	205	196	390	698

Using this method, a set of texts was obtained, which were analyzed through thematic modeling (Walkowiak & Gniewkowski, 2020), using the “Multilingual Topic” tool, provided by the CLARIN-PL scientific infrastructure, via the webservice portal (<http://ws.clarin-pl.eu/>). This set was cleaned by removing the texts containing only page navigation commands, which reduced the number of texts analyzed. The method assumes the separation of strings of non-accidentally occurring words by: (1) creating a model of the co-occurrence of words (how often words accompany each other in the corpus and individual texts), and (2) calculation of the probability of occurrence of individual words in a random text drawn from the corpus. Then the words were combined into so-called topics, i.e., sets of co-occurring words. With the help of statistical activities, such sets of words have been distinguished, which probably do not coexist with each other accidentally (the sum of the probabilities of occurrence must equal 1). The latent dirichlet allocation (LDA) algorithm (Nicolas, Kim & Chi, 2021) and additive regularization of topic models (ARTM) were used to extract the fuses. It allowed the determination of thematic consistency, i.e., content connections of the meanings of words that make up a single topic. The results are presented in graphical form. At the same

to be maintained and complemented by new lines of action. The chosen climate neutrality allows the city's transformation to be supported by European funding for this purpose (European Commission, 2021).

Discussion

Sustainability issues should go hand-in-hand with the smart city concept, especially in relation to smart mobility. The results of this study indicated that city communications contain limited information on transport in the context of sustainability and the use of ICT in the city. The work of Ahvenniemi et al. (Ahvenniemi et al., 2017) also provided an interesting indication that the issue of transport is associated with environmental and social issues, rather than economic ones (impact categories). It is noteworthy that, in both types of rankings, they are relatively poorly represented: for the smart city model, 7% of the total number of indicators was identified (36 out of 510), and for urban sustainability 11% (49 out of 448) related to transport. Our results also indicated a relatively small presence of the transport thread on the pages of cities selected from the smart city rankings, as evidenced by its appearance in a single number of topics for each of the keywords. These can be related to the mobility scenarios up to 2030, in which Miskolczi et al. (Miskolczi et al., 2021) identified automation, shared mobility, and electrification as the main themes to address road congestion, social attitudes, and GHG emissions.

The topics obtained in the study also included key terms relating to the main problems identified in the literature by Miskolczi et al. (Miskolczi et al., 2021): congestion, pressure, and accessibility. The generated word clouds do not refer directly to solutions to these problems but contain references to mobility management (topic No. 11), e.g., planning, decision, and development, which can be interpreted as evidence of a more extensive solution to mobility problems – through infrastructure development (design, study, and grant) and influencing the way it is used (transit, plan, corridor, use, accessibility, and location – topic No. 2) in specific locations (neighborhood and area). In the observation of the websites of the studied cities, one can notice the limited presence of the mentions of smartness in marketing communication. According to Trindade et al. (Trindade et al., 2017), the smart city concept should be seen as a vision, a manifesto, and a promise to represent a sustainable and ideal form of the 21st-century city. According to Starc-Pecena et al. (Starc-Peceny,

Maček & Ovin, 2017), smart city marketing should not only be based on sustainability issues presented in specific messaging but should seek to co-design economic policies by the local community.

The limitations that occurred in our study can be grouped in relation to the data source and its characteristics, the object of analysis and its diversity, and the use of the research tool. The first challenge was the multilingualism of the data, in which natural language messages were formulated. The difficulty, in this case, is related to the translation of keywords, which determines the effectiveness of the search into the original language. A manifestation of this difficulty was, for example, the lack of texts retrieved from the Athens website. A feature of the sources used was the potential richness of the content accessed by the CLARIN tools. However, it turned out that keywords are also not consistently used by the authors of the messages on the source pages, indicating the need to adapt the method used in subsequent studies. Moreover, with a small number of messages or objects under study, specific events or situations can significantly affect the results obtained. This is because they become embedded in the information resources of the website, e.g., through a large number of messages on a given topic, which leads to the overrepresentation of a given concept in the word cloud generated by the multilingual topic. The tool itself provides the possibility to eliminate random words within the so-called “stop list”; however, its use means interference of the researcher in the collected source data and should be used with great caution.

The subject of analysis, where the city services' own communications are in a natural language, is generated by those responsible for external communication. Outside the scope of the study remained the messages of residents and other stakeholders available, for example, in social media. Insight into this area of information is planned for the next stages of the research project, as the tools available through the CLARIN infrastructure continue to develop. The survey we conducted also highlighted differences in the level of communication activity between cities. The information available on their official websites was obtained from different years, which determined the degree of validity of the data obtained and, consequently, the quality of the results obtained, and conclusions formulated.

Finally, the use of the research tools themselves – despite full support of the process by the CLARIN staff – requires multiple testing to minimize the risk of misinterpretation of the results. In order to

eliminate the noted limitations, it is advisable to involve researchers speaking the natural languages of the material under study in the research process (at the stage of designing the study and collecting data) and confirming their consistency. This pilot study has revealed points in the research design that needs to be corrected, and their improvement in the next phase of the research will allow the potential of the tools used in the current study to be exploited to a greater extent.

Conclusions

The concepts of the smart city and the sustainable city have many common features. In our view, a modern city should strive to meet the needs of its inhabitants by making use of modern technologies, but at the same time caring for sustainable development. Our conclusions concern three areas: the methods used, the link between transport and a sustainable and smart city, and the marketing use of smart city rankings. The applied topic modeling methods allow us to recognize the data available in the source languages and can, therefore, be considered promising for further research. This is also important because analysis of texts on websites that are not only in English but in the languages of different countries (e.g., Italian, Russian, Greek, etc.), is possible. The issue of transport, in the light of the collected data, does not seem to be sufficiently present either among the criteria of smart city or sustainable city rankings. The surveyed cities do not seem to be interested in marketing the use of the potential behind the position in the smart city rankings. In our opinion, the use of the smart city title should be widely promoted on websites, in order to build awareness of the city's assets among stakeholders. When the city authorities inform the public about projects related to improving the quality of life of its inhabitants, implementing innovative technologies, caring for the environment, etc., the inhabitants will become more involved in these activities, helping to implement them more quickly. This paper opens the field up to further research on the multifaceted approach to the role and importance of transport in the smart/sustainable city model.

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Economics, Management and Quality Science

The impact of the human factor on the functioning of the quality management system in the enterprise

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Abstract

This article analyzes the expectations of the management board and managerial staff as opposed to the expectations and concerns of regular employees of the company. Communication between the decision-making and executive groups is presented as one of the key elements determining the proper operation of the quality management system in the enterprise. In the practical part, the results of the research covering the management and regular employees were presented and compared. The research is aimed at diagnosing the quality of information flow in the enterprise based on the quality management system in the assessment of both surveyed groups, determining the perception of the importance and scale of participation in the proposed corrective actions among the surveyed groups of respondents, and diagnosing the level of informing rank-and-file employees about the goals and importance of conducting internal and external audits. The research also covered the role of lower-level employees in the effective functioning of the company's quality management system. An attempt was made to analyze the degree of participation of regular employees in the functioning of the quality management system in the enterprise. The article ends with the conclusions and proposals for future research.

Introduction

In every enterprise, regardless of whether it is a small or large enterprise, either with a production, commercial, or service profile, the introduction of a quality management system and the obtaining of an ISO certificate is a very serious and costly undertaking. The decision to obtain a quality certificate may be caused by the desire to move the business to a “higher level” in terms of quality standards (it is easier to gain the trust of a new customer if the company can present the ISO certificate at first contact, thus documenting the high level of its services) or it may be simply forced by circumstances. Often

concluding a long-term contract with an important client is conditional on holding such a certificate.

Obviously, obtaining a certificate of quality is associated with meeting a number of specific requirements by the company and it is never easy to attain. This is regardless of the fact whether the company has already had a dynamic quality department, or it is just trying to organize everything from the beginning in accordance with requirements (Barbosa, Oliveira & Santos, 2018).

In this article, we draw attention to the often-underestimated factor on which the entire success of a difficult undertaking depends, which is making the quality management system in the company to

not only have good-looking documentation, but also a great tool that facilitates work, which allows an elimination of errors or mistakes in production processes, customer service, or in the management of warehouse resources, and – or perhaps most importantly – in saving funds.

Such a factor is the human factor, that is simply the people employed in the company and their attitude – at all levels, from the management team and ending with the production workers or security services. The basic mistake resulting from the fact that the quality management system is dedicated to the managerial staff, and not regular employees, is their omission and marginalization of their role in the process of implementing the quality management system. Such a situation leads to a hypothesis that the human factor is one of the key elements inhibiting the process of implementing the quality management system in the enterprise. The aim of the article is to verify this hypothesis in practical terms, based on the actual realities of the functioning of the quality management system in enterprises that are not only theoretical, which often use idealized assumptions (Nováková, Čekanová & Paulíková, 2016; Bravi, Murmura & Santos, 2019).

Expectations and fears of the management staff versus expectations and fears of employees

Speaking of the expectations as to the usefulness of the quality management system itself and the concerns related to its introduction and certification, the division is very traditional: management versus lower-level employees. In the process of introducing a quality management system, one should be aware of the most important fact faced by anyone who has ever managed a team, no matter if it is big or small: people do not like change. It is a psychological condition that cannot be fought against, but that can be “tamed” and sometimes even used to achieve the intended goals.

While the expectations of the management staff result from various sources (better organization of work, easier customer acquisition, higher prestige of the company etc.), the fears are always related to the same thing: costs. The costs are caused by the fees related to certification and work related to the preparation of documentation and training of employees, as well as the implementation and commissioning of the system.

On the other hand, when it comes to employees, especially at lower levels, there are considerably

more fears than the expected benefits. These include: anxiety related to the fear of increasing the obligations related to the introduction of new documentation, new guidelines as to how to perform work, and reluctance to training, which is often completely inappropriate to the audience and usually does not explain too much to lower-level employees. This situation creates a barrier that is difficult to overcome. Experienced managers that manage teams of employees should, in principle, be able to prevent such situations. Nevertheless, this article may be helpful for them when trying to solve problems during the implementation of the quality management system in the enterprise (Zgodavova, Hudec & Palfy, 2017).

Communication in the enterprise as a way of detecting problems

As mentioned before – people do not like changes, even if these changes in principle lead to the improvement of the situation of these people, to make their work easier, or to increase their effectiveness and efficiency. It is obvious that taking steps to introduce a quality management system in a company must be preceded by the management noticing the expected benefits.

While the management staff, in most cases, sees the obvious benefits of introducing the system and the difficulties and costs associated with the preparation of the entire process, it usually neglects the most important aspect in managing human teams: proper communication. Such an approach leads to a situation where the quality management system remains only a paper certificate, and the troublesome supplementation of documentation just before the expected external audit and the state of general panic before this audit creates difficulties, while the essence of the quality management system itself is completely different: simplifying work and eliminating potential errors.

A very important question needs to be asked: why is this happening? The diagram shown in Figure 1 may be helpful in answering this question. As shown in this figure, the scope of competences is clearly defined: the management board has the largest one, then the representative for the quality management system, who is responsible for the preparation of documentation regarding the processes taking place in the company and the functioning of the system itself, and the leaders of individual processes. These are the people with decision-making competences – they make decisions about the process itself, prepare

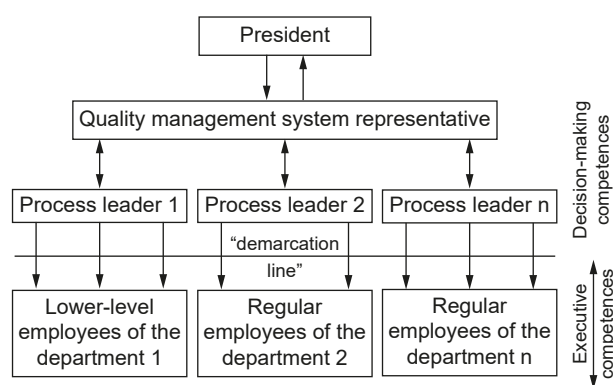


Figure 1. Decision scheme for the implementation and subsequent operation of the ISO system

documentation, define its form, dates, and course of internal audits, records documentation regarding changes or corrective actions, and take part in external audits. On the other hand, people with executive competences are employees of particular departments: e.g., production workers, warehouse workers, and maintenance workers.

The division between persons with decision-making competences and persons with executive competences, shown in Figure 1, has been marked as “demarcation line” – not by accident. As simple surveys show, the role of the human factor as a supporting or inhibiting factor is clearly underestimated: the flow of information is not fluid.

The first rank in the company’s hierarchy, which is both the most decisive unit and the one that can turn into the strongest factor inhibiting correct actions, is the company’s management. The management board is also responsible for organizing internal and external training for employees, including not only general information on the quality management system and ISO standards, but also outlining the benefits of introducing such a system and certification (Marques et al., 2018).

For the purposes of this article, the position of the quality management system representative was retained because, although since 2015 such a position is no longer required, for pragmatic reasons it still functions in most companies that have an implemented quality management system. This position may have different names, e.g., director of internal audit and certification. Such an employee still watches the dates of audits, supervises the documentation, has responsibility for contacts with the certification body, and removes non-conformities in the system, maintaining its integrity. Process leaders are responsible for the correct (i.e., compliant with the quality management system) course of work in a given

department, for keeping systematic records in the documentation and reporting inaccuracies.

Unfortunately, while these three levels – management board, quality management system representative, and process leaders – have quite close contact with each other and information usually flows between them, without major problems, all three levels usually forget that communication with employees should be equally smooth, or maybe even more efficient. It is the employees at the lower level that most of the problems with the correct application of the quality management system lie (Pacana & Ulewicz, 2020).

Research methodology

The subject of the research centers on the opinions of the management staff and the regular employees regarding the processes related to the functioning of the quality management system in the company. The aim of the conducted research was to:

- determine the discrepancy between the expectations and concerns of the management staff and the expectations and concerns of regular employees regarding the functioning of the quality management system in the company;
- diagnose the flow of information in the enterprise for the quality management system in the assessment of both surveyed groups;
- examine the perception of the importance and scale of participation in the proposed corrective actions among the surveyed groups of respondents;
- diagnose the level of information about the goals and importance of conducting an external audit in the surveyed employee groups;
- determine the frequency of informing rank-and-file employees about the results and conclusions of the external audit.

The pilot studies were carried out by means of a direct telephone interview or instant messaging that enabled connections to mobile numbers. It was assumed that the interview would be conducted in 50 enterprises, six for each enterprise (two interviews with the management staff and four interviews with the rank-and-file employees of randomly selected departments). The selection of the research sample was deliberately from a group of small and medium-sized enterprises. The questionnaire was completed by the interviewer on the basis of the respondents’ answers. Each questionnaire was given a unique code to correlate the responses of the management and rank-and-file employees of the company. The research, with the consent of all respondents,

was conducted in March and April 2022. 25 companies, including 15 from Poland and 10 from abroad, from countries such as the Netherlands, Turkey, France, and Italy, expressed their willingness to participate in the survey. Considering only the pilot nature of the research, it was found that it would be a sufficient research sample.

The companies participating in the study represented a production, commercial or service profile, and the main criterion was that they needed to have a quality management system implemented. The questionnaire contained 10 closed questions and the possible answers were within the forced-choice scale. This allowed an omission of the neutral point in the responses (the error of the central tendency was eliminated) and, thus, more adequate results were obtained. After counting all the answers, the percentages were assigned, and rounded up to integer values. The obtained results are presented in charts or tables.

Presentation of research results

The first question in the questionnaire concerned the organization of training (internal and external) in the field of the quality management system for the company's employees. Almost the entire management staff (95%) indicated that such trainings were conducted. Only 5% of the management did not know about conducting such trainings. On the other hand, the employees' answers indicate that 27% knew about the trainings conducted, 50% are not aware that such trainings are organized, and 23% say that they are not organized. The answers obtained for this question are presented in Figure 2.

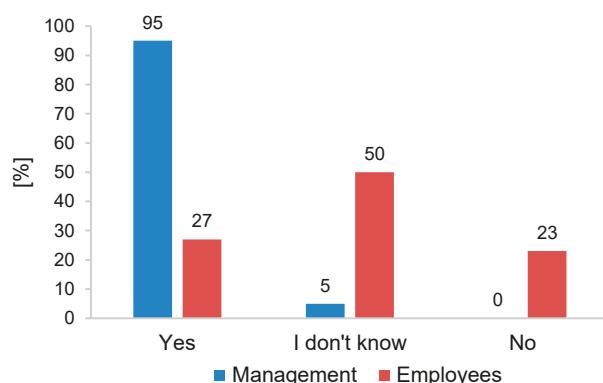


Figure 2. Organization of training (internal and external) on the quality management system

In the next questionnaire, the respondents were asked to evaluate the organized training (internal and external) in the field of ISO quality standards.

A four-level grading scale was adopted, from very good to unsatisfactory. The management staff assessed the training as very good (50%) or good (30%); 10% assess them as sufficient and only 5% as insufficient. On the other hand, only 10% of employees assess the training very well, 35% as good, and 40% as satisfactory. 15% of regular employees judged the training as insufficient. The responses obtained for this part of the questionnaire are shown in Figure 3.

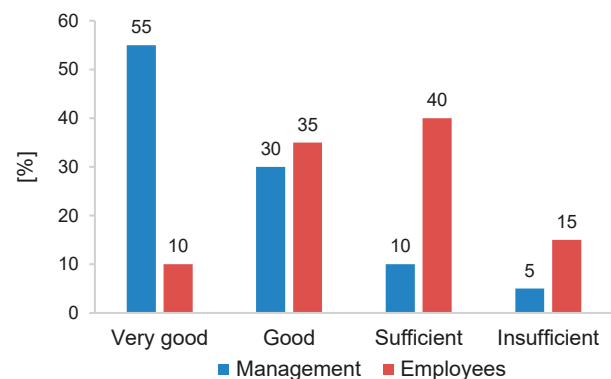


Figure 3. Assessment of the training courses (internal and external) conducted in the field of ISO quality standards

For the next question, the respondents were asked to indicate how often non-management employees participate in the process of preparing procedures functioning in the enterprise. More than half (55%) of management indicated that regular employees are never involved in the preparation of procedures. Similarly, as much as 60% declared that it "never" occurred among regular employees. In both groups, 30% answered "very rarely". None of the surveyed groups indicated "always" and only 2% of the management provided the answer "very often". The results of the answers to this survey question are summarized in Table 1.

Table 1. Frequency of participation of non-management personnel in the process of preparing procedures

Response	Indication [%]	
	Managers	Workers
Always	0	0
Very often	2	0
Often	3	2
Rarely	10	8
Very rarely	30	30
Never	55	60

In the next questionnaire, an attempt was made to determine how often non-management employees

participate in the process of preparing documentation on the quality management system in the enterprise. The overwhelming number of regular employees provided the answer “very rarely” (45%) or “rarely” (30%). The answers “always” and “very often” received no indications; the management team responded on a similar level. The results of the answers to this survey question are summarized in Table 2.

Table 2. Frequency of participation of employees who are not management staff, in the process of preparing documentation concerning the quality management system in the enterprise

Response	Indication [%]	
	Managers	Workers
Always	0	0
Very often	10	0
Often	20	5
Rarely	25	30
Very rarely	35	45
Never	10	20

The next survey question concerned the frequency with which the management team consults with regular employees on proposed corrective actions. None of the regular employees indicated the answer “always”, while the answers “very rarely” and “never” were indicated, respectively, by 35% and 25% of the respondents from this group. On the other hand, the predominant responses in the group of executives were “very often” (27%). The answers to this question for individual respondent groups are presented in Table 3.

Table 3. Frequency of consultations by the management of the proposed corrective actions with employees

Response	Indication [%]	
	Managers	Workers
Always	13	0
Very often	27	5
Often	10	15
Rarely	20	20
Very rarely	20	35
Never	10	25

In the next question, the respondents were asked to indicate how often the rank-and-file are informed about the objectives of changes to the procedures and documentation existing in the company. Half of the rank-and-file stated that they are

never informed about the purpose of changes to procedures and documentation in the company. In this group of respondents, no-one indicated the answers: “always” and “very often”. The management staff, on the other hand, answered “always” (20%) and “very often” (15%). The same percentage of respondents in this group indicated “very rarely” and “never”, respectively. The responses to this questionnaire for individual respondent groups are presented in Table 4.

Table 4. Frequency of informing employees about the goals of changes in procedures and documentation

Response	Indication [%]	
	Managers	Workers
Always	20	0
Very often	15	0
Often	22	10
Rarely	8	15
Very rarely	20	25
Never	15	50

The seventh question in the questionnaire was to answer whether the company had a formalized way of submitting proposals for changes by employees at all levels. 70% of executives replied yes and 25% said no, while 5% replied “I don’t know”. A reverse trend of responses occurred among the rank-and-file of employees. This group of respondents said (60%) that the company did not have a formal way of submitting proposals for changes, and only 5% said yes. A relatively high percentage (35%) of regular employees provided the answer “I don’t know”. The answers to this question for individual respondent groups are presented in Figure 4.

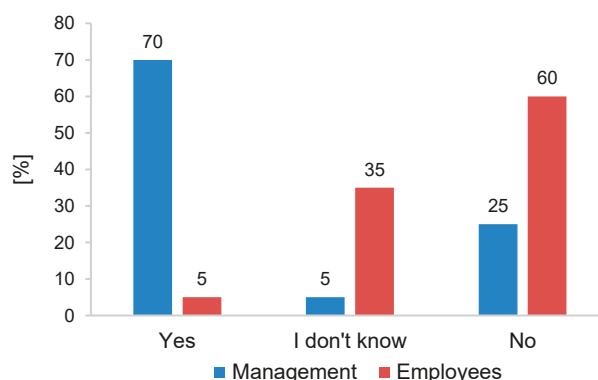


Figure 4. Existence of a formalized way of submitting proposals for changes by employees at all levels in the company

In the next questionnaire, the respondents' task was to assess the benefits of introducing ISO

standards to the enterprise on a four-level scale. Individual groups of respondents provided basically opposite answers to this question: the management team assessed the benefits of implementing ISO standards in the enterprise very highly or highly (55% and 40%, respectively), while the group of employees assessed the opposite (insufficient 50%, sufficient 35%). The answers to this question for individual respondent groups are presented in Figure 5.

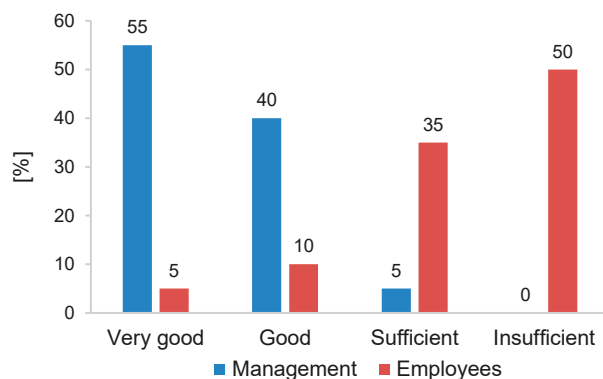


Figure 5. Assessment of the benefits of introducing ISO standards in the enterprise

The ninth survey question was to answer how often employees are informed about the objectives of the external audit. This question was most often answered by management staff “very often” (55%), while a quarter of regular employees indicated the answer “rarely” and one fifth as “very rarely”. Detailed answers to this question for individual respondent groups are presented in Table 5.

Table 5. Frequency of informing employees about the objectives of the external audit

Response	Indication [%]	
	Managers	Workers
Always	10	0
Very often	55	12
Often	15	15
Rarely	10	25
Very rarely	10	20
Never	0	28

The last question in the survey questionnaire concerned the frequency of informing rank-and-file employees about the results of the external audit. More than a third of regular employees (35%) answered “never”, a fifth (20%) “very rarely”, and 25% answered “rarely”. Similar results were obtained in the group of management, but the

highest percentage of respondents (30%) indicated the answer “very rarely”. Detailed answers to this question for individual respondent groups are presented in Table 6.

Table 6. Frequency of informing employees about the results of the external audit

Response	Indication [%]	
	Managers	Workers
Always	5	0
Very often	10	5
Often	15	15
Rarely	20	25
Very rarely	30	20
Never	20	35

Discussion

The questionnaire surveys regarding the organization of training in the field of the quality management system clearly indicate that the management staff had a different opinion from the regular employees. Managers are knowledgeable about the conducted trainings and evaluate them mostly very positively. Regular employees, on the other hand, do not have any knowledge of the conducted training and most often judge it as sufficient. This indicates an evident lack of proper information and a maladjustment of the scope of training addressed to specific groups of students (Araújo et al., 2019).

The role of rank-and-file employees in the process of preparing procedures is perceived by both surveyed groups in the same way. There is a convergence in the opinion that the role of rank-and-file employees is negligible or nonexistent. This clearly indicated that the potential of regular employees is not a significant element in the preparation and implementation of procedures in the enterprise. This phenomenon is by all means undesirable. Why not take advantage of their experience and competences when having qualified employees? Especially when the positions are filled by appropriately selected staff who know the process in practice (Micklewright, 2010; Santos & Milán, 2013).

The participation of regular employees in the process of preparing documentation, understood among others as all kinds of forms, product sheets, specimen lists, shipping documents, etc., is assessed as adequate. This phenomenon is disturbing, because it is at lower-level positions that the knowledge about what is needed for the efficient functioning of a given department of the company is located. The major

mistake of the management team is to 'give up' the possibility of acquiring this knowledge.

Equally rarely does the management consult with the rank-and-file employees on proposed corrective actions. However, in the opinion of the management it is much more frequent than in the opinion of regular employees. This may result from the incorrect assumption of the management that the actions they propose are optimal, so there is no need to consult them with regular employees.

When asking the question on the frequency of informing regular employees about the advisability of changes made in procedures and documentation, the research results clearly indicated that in the opinion of regular employees they never receive such information. The overwhelming majority of management say that such information is sufficiently communicated. This proved that the information provided by the management is given in an incomprehensible, insufficient, or inadequate manner.

As for the questions related to the frequency of informing lower-level employees about the objectives and results of the external audit, unfortunately regular employees mostly answered "very rarely", "rarely", and "never"; if the management staff replied "very often" about the objectives of the external audit, he does not see the need to inform rank-and-file employees about its results. Such a procedure could be harmful to the company because it does not lead to an improvement in its bravery and is demotivating for the employees (Caridade et al., 2017; Fonseca et al., 2017).

As the survey research shows, the assessment of the situation regarding the implementation of the quality management system and its functioning is diametrically different in both groups. Almost everywhere in which the management staff provided positive answers (very good, good, very often, and yes), we see negative answers from a group of regular employees (insufficiently, never, very rarely, and no). This discrepancy in the responses between the two groups of respondents may indicate that the expectations of the management board, and proxy and process leaders, do not coincide with the expectations of regular employees, and certainly not their concerns.

It is especially visible in the questions regarding the involvement of regular employees by the management (i.e., those responsible for the implementation of the quality management system), and the participation of these employees in the creation of procedures and documentation in the company (Boiral, 2011).

Conclusions

As the research has shown, there is no proper communication between the analyzed groups of regular employees and management. This results in a malfunction of the quality management system in the enterprise and, as a result, leads to a reduction in efficiency. One of the key examples may be the fact that, in the surveyed companies, there is still a person acting as a quality management system representative. Although according to the current ISO standards, such a function is no longer required. This change was caused by the hope for a greater activation of employees from all departments of the company in the quality management process, while such a policy not only did not obtain the expected results, but even led to a blurring of responsibility and practically a destruction in the quality management system.

This results in a situation in which the management board, and the person acting as the representative for the management of the quality system, still have decisive action and lower-level employees are not involved in the actual action. In such a situation, due to the lack of sufficient communication, lower-level employees are not able to perceive virtually any benefits of having a quality management certificate by the company. In extreme cases, employees treat it as a "whim" of the management board, unrelated to the actual work of the enterprise. They cannot see any other effects than the need to fill out additional documents, comply with new restrictions, and change existing habits.

Unfortunately, this approach discouraged people from working and because, as mentioned above, people generally do not like changes, they attempted to show that these modifications were not only unnecessary, but also harmful – and this already leads to a decrease in work efficiency and, as a result, a decline in the company's profitability. At best, the quality management system remains a dead recipe; the only function of process leaders is to fill out paperwork just before audits (especially external audits that extend the validity of the certificate) and provide unnecessary corrective actions.

It seems justified that it is enough to break the barrier of the lack of communication, trying to use both negative and positive information from lower-level personnel, which will help lead to a situation in which the quality management system in the company meets the assumed criteria. It should also be noted that this issue is rarely discussed in the scientific literature and, so far, has not seen either

broad, in-depth studies or practical solutions to this problem.

The results of these pilot studies induce the need to undertake further, extended questionnaire studies aimed at determining the relationship between the communication of lower-level employees and management staff that have a decisive impact on the optimization of processes, which involves reducing losses and costs and saving time. Such research allows for the pragmatic determination of the determinants of the functioning of the quality management system in the enterprise to enable a use of the available tools to the maximum.

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Hazard, risk assessment and safety management in workstations with lasers – theoretical and practical studies

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Abstract

Hazard identification and occupational risk assessment, defined as the probability of occurrence of unfavorable work-related events, is one of the areas of activity for employers in relation to current legislation and standards. Using occupational risk assessment it is possible to design and use workstations properly, respecting workers' health. This article presents an issue related to the use of workstations with laser equipment, which describes the nature of work of lasers and the specific impact of the laser beam on the material. The subject of the analysis is the workstations with a CO₂ laser for cutting polymers and a workstation with a fiber laser for marking and engraving. For the above-mentioned workstations, using a designed checklist, the features of lasers are verified, hazards are identified, and occupational risk is estimated using the risk graph method. The estimated risk at selected workplaces with lasers clearly indicated that special attention should be paid not only to the device, and the negative impact of their laser beam on the human body, but also on the treated materials. The article also draws attention to protective measures, which should be applied at laser workstations to ensure the safety of employees.

Introduction

The appearance of machines in production halls, with various types of components used to process materials, was synonymous with the appearance of an aspect of potential danger to workers. The diversity of machines and technologies has meant that the identification, assessment, and management of the risks posed by machines and equipment at workstations remains a topical issue to this day.

The machinery and equipment used today are a source of various risks. In addition, with the

development of technology and the state of knowledge, new equipment is being constructed and popularized. This state of affairs makes it necessary to constantly analyze and assess the potential exposure of operators of such machines and equipment to health impairment or occupational diseases developing in the long term. The risk of health damage is most often the result of incidents directly related to work performance and may lead to occupational accidents or adverse health effects. It is the duty of the employer to ensure safe working conditions, to protect the health of workers and, therefore,

to continuously assess the safety condition of the workplace (Pacana, 2019). Management of workplace safety is linked to the assessment of occupational risk, which determines whether a hazard on the job is acceptable or not (Łunarski, 2006). Once a risk assessment has been carried out, it is possible to plan and design safety activities and technical solutions. It is also assessed whether the protections already in place are appropriate and sufficient, which is why various types of alarms, sensors, guards, safeguards, and workers' protective clothing and equipment (OSHA, 2022) are installed in workplaces or on machines.

However, due to the continuous development of technology and the implementation of new, innovative manufacturing technologies, new devices are constructed and used, different from the existing ones, which may also be the source of new factors threatening humans. An example of such a dynamically developing technique is laser technology. Although lasers are not a new invention, as the first lasers appeared in the 1960s, they are constantly being modernized and find application in many fields of science and technology (Thyagatajan & Ghatak, 2010).

In the context of processing engineering materials, lasers are used for surface treatment – hardening, alloying, surfacing, marking, and engraving, as well as for welding, cutting, hollowing, and powder sintering of hard-to-machine materials (Kusiński, 2000; Sołtysiak, Sołtysiak & Wasilewski, 2019). In product design, processes lasers are used for scanning components in, e.g., revers/reconstruction engineering (Ciecńska, 2021) and in production for monitoring, e.g., automated production line, counting products, and quality control by laser measurement and identification of defects in products (Thyagatajan & Ghatak, 2010; Panasiuk & Kaczmarek, 2014; Kaczmarek, Panasiuk & Tomaszuk, 2015). In addition, lasers are utilized for research purposes in a number of measuring devices at test stands for phenomena that are later used in practical applications (IMP, 2022).

Of course, the above description does not limit the fields of application of laser devices. This fact may indicate that the characteristics of lasers are so interesting that even in recent years, in connection with the Industry 4.0 revolution, an intensive change in manufacturing technology is visible in favor of replacing conventional techniques with laser techniques (Industry 4.0, 2017; Ciecńska, Więcek & Gągała, 2018). The increasing ubiquity of the use of laser equipment leads us to analyze the risks and

pay attention to important aspects of safety management in the context of workstations with lasers (Nakamura & Carroll, 2011).

Laser activity and phenomena in contact with matter

Laser radiation does not occur naturally in nature. It is generated by a device called a laser (light amplification by stimulated emission of radiation) and can have a wavelength in the range of 180 nm (or shorter) to 1 mm (PN-EN 60825-1). Laser radiation is monochromatic and highly coherent in time and space. The laser beam propagates directionally, can cover very long distances, and can be focused in an applied optical system, which enables the creation of a considerable power density, as stated in (CIOP, 2011), even up to 10^{10} W/cm². Laser operation consists of the excitation of the active medium by optical pumping (i.e., via arc lamps, flashes, or other lasers, e.g., semiconductors), electrical pumping (gas discharges or laser diode power supply), chemical pumping, or electron collisions. The excited active medium emits energy in the form of a coherent radiation quantum (Ziętek, 2008). By directing a laser beam, it is possible to induce various phenomena on the surface of the matter on which it falls. The nature of the impact of the beam on matter can be continuous or pulsed.

Impact on construction materials

The “laser-matter” interaction in solids initiates a number of different phenomena, not yet fully understood: ejection of atoms, ions, molecules, and fragments of matter, generation of shock and sound waves, initiation and expansion of plasma, as well as a combination of these processes (Marczak, 2004). In general, the interaction of a laser beam with a solid body is divided into three phases, as shown in Table 1.

The laser cutting analyzed in the following section may proceed with the initiation of reactions (Kołodziejczak, 2015):

Table 1. Phenomena in the three phases of laser action (Marczak, 2004)

Phase	Phenomenon
Absorption	Reflection, penetration, absorption waves, surface shaping effects
Desorption/ Ablation	Evaporation, removal of evaporated particles, boiling, shock, and sound waves
Relaxation	Surface tension, chemical and metallurgical effects (e.g., hardening)

- combustion of the material – the laser beam falls on the surface, heats it in the cutting gap area to ignition temperature, and then oxygen is supplied to intensify the combustion process;
- melting and blowing of material – the laser radiation delivers enough energy to melt the material located on the cutting line, the liquid material is then removed using a technical gas such as nitrogen or argon;
- vaporization of material – occurring at a high temperature, the material at the cutting place is rapidly heated to boiling point and brought to a gaseous state.

In laser marking and engraving, on the other hand, color effects or engraving are achieved by (TROTEC, 2022):

- annealing – the heat effect of the laser beam causes an oxidation process underneath the material surface, resulting in a color change on the metal surface;
- staining – the heat effect generated by the laser beam causes a chemical reaction in the material, which depends on the material composition, resulting in different color shades;
- engraving – the workpiece surface is melted and evaporated with the laser. Consequently, the laser beam removes the material;
- removing – the laser beam removes the topcoats applied to the substrate. Contrast is produced as a result of the different colors of topcoat and substrate;
- foaming – the laser beam melts a material. During this process, gas bubbles are produced in the material, which reflect the light diffusely. The markings will, thus, become lighter than the areas that have not been etched;
- carbonizing – the laser heats up the surface of the material (at a minimum of 100°C) and oxygen, hydrogen, or a combination of both gases is emitted. A darkened area with higher carbon concentration appears.

Impact on the human body

The energy released in the laser beam also affects human tissues. The delivery of energy causes it to be absorbed by the tissues, increasing the kinetic energy of the particles, manifested by vibrations. As a result, the temperature of the tissues increases and, above 45°C, the cell membranes are ruptured and the tissues are sintered. Above 60°C, they are partially vaporized, resulting in tissue necrosis. If the temperature continues to rise to approximately 100°C,

the water in the tissues begins to boil; above 150°C, proteins become charred. Effects can be observed not only in the exposed area but also around it, the extent of necrotic changes depends on the duration of exposure. The impact described above is defined as the thermal impact (CIOP, 2011).

In addition, photochemical interactions, for radiation with characteristic wavelengths below 600 nm, cause damage to tissues as a result of molecular absorption of radiation. Chemical reactions take place in the tissues resulting in tissue damage. These reactions occur with short-term exposure but with significant radiation absorption by the tissue. In the human body, tissues with high absorption are the lens and the retina. They can undergo irreversible changes. For the retina, radiation in the range of 400 nm to 1400 nm poses the greatest threat as it enters the eye and is focused on the retina. The pathological changes to the eye can be varied, and they are wavelength-dependent (Table 2).

Table 2. Laser wavelength and pathological changes of the eye (Directive, 2006)

Laser wavelength	Type of eye disease
180 nm – 315 nm	Inflammatory corneal damage
315 nm – 400 nm	Cataract
400 nm – 780 nm	Photochemical and thermal damage to the retina
780 nm – 1400 nm	Cataract, retinal burn
1,4 µm – 3 µm	Corneal haze, cataract, corneal burn
3 µm – 1 mm	Corneal burn

Typical situations where damage to the eye occurs include:

- direct viewing of a beam (also reflected from a smooth surface) or prolonged viewing of a diffuse beam. The retina may become red, irritated, or edematous and visual acuity may deteriorate;
- the reflected beam – e.g., from smooth, mirrored surfaces (i.e., a rolled sheet metal or polished metals), or short exposure to low-power radiation causes tissue damage. In the case of reflection of a beam partially absorbed by the material from which it is reflected, the damage occurs at higher laser power.

Due to the structure of the human eye, and its ability to focus radiation falling on the cornea to a small spot on the retina, it is particularly dangerous for lasers with wavelengths of 400–1400 nm. Calculations (CIOP, 2011) show that a laser beam with a power density of 10 W/m² in the pupil plane will be converted to a density of 5 MW/m² in the retinal plane (power density may even be increased

by about 500,000 times). Radiation outside the specified range should also not be underestimated.

Human skin is exposed to damage to a similar degree as the eye. Also in the case of the skin, a reflected and scattered beam causes the penetration of radiation to a depth depending on the wavelength. Radiation is absorbed and dispersed in skin tissues and can penetrate the epidermis, dermis, and subcutaneous tissue. Tissue heating may occur, giving rise to various pathological effects from hyperpigmentation to redness and swelling to the local coagulation. The wavelengths of radiation from 400 to approximately 1400 nm penetrate deepest into the hypodermis. Sometimes changes are not visible on the surface of the skin, but deeper tissues can be damaged, which take longer to heal and complications may occur during treatment (CIOP, 2011).

Paradoxically, the undesirable consequences of exposure to laser radiation in the processing of construction materials can be used during medical procedures, when changes in tissues are induced in an intentional way. The use of laser scalpels, coagulators, and biostimulation lasers is also very popular (Owczarek & Wolska, 2008; Łabędzka, Jędrusiak & Wasilewska-Michalak, 2011; Chen et al., 2013). In each case, however, the limits of this impact must be defined.

Other risk factors for laser devices

The health safety issues mentioned earlier do not represent the whole subject of exposure to harmful

factors in working with lasers. The occupational risk assessment should also study other risks that arise from the use of such technology. These are mainly (Owczarek & Strawiński, 2012):

- hazards caused by the operation of laser equipment: not only laser radiation, but also associated radiation, e.g., high-frequency radiation and X-rays, and electrical hazards;
- risks due to the use of additional substances necessary for processing or those that arise during processing, as well as fire or explosion hazards – use of working gases such as air/oxygen, argon, nitrogen e.g., when cutting polymers (Sims, Ellwood & Taylor, 1993; Kołodziejczak, 2015), formation of vapors, gases in reaction with the processed material (sometimes very harmful, as shown in Table 3; for this reason, cutting, e.g., PVC is not practiced), and sparking and ignition of materials;
- hazards due to the type of room and the workplace environment – unsuitable floor covering materials, desktops, windows that let radiation outside, too low lighting with an unshielded beam (causing excessive dilation of the pupils of the eyes), and shiny rather than matt walls;
- awareness of persons temporarily or long-term connected with the workplace – disregard of the danger, especially in the case of an invisible laser beam, switching off sensors, shielding locks due to apparent convenience of operation, and lack of markings in the workplace.

Due to the different degrees of severity of the effects of the laser beam on the human body, lasers

Table 3. Examples of compounds emitted during laser cutting of selected polymers (Sims, Ellwood & Taylor, 1993)

Material cut	Cut-assist gas			
	Argon		Air	
Polycarbonate	Benzene	Naphtalene	Benzene	p-Cresol
	Toluene	Alkanes	Toluene	m-Cresol
	Styrene	Benzofuran derivative	Styrene	Benzofuran derivative
	Phenol		Phenol	
PVC	Benzene	Benzaldehyde	Benzene	1-Propynylbenzene
	Toluene	Naphtalene	Toluene	1,3-Butadienylbenzene
	Alkanes	Methylmethacrylate	Styrene	Naphtalene
	Styrene	Methylcyclohexane	Alkanes	
		Chlorobenzen		
PMMA	Toluene	Methylmethacrylate	Toluene	Methylmethacrylate
	Xylene	Trimethylbenzene	Xylene	Trimethylbenzene
	Alkanes		Alkanes	
PET	Benzene	Alkanes	Phenol	Alkanes
	Toluene	Phenylacetylene	Benzene	Phenylacetylene
	Xylene	Benzaldehyde	Toluene	Benzaldehyde
	Styrene	Methyl phenyl ketone	Styrene	Methyl phenyl ketone
Epoxide-glass	Toluene	Z-2-Heptenal Tridecanol	Xylenes	Tridecanols
	Xylenes	Trimethylbenzene	Alkanes	Trimethylbenzene

have been divided into classes and assigned mandatory safety requirements within the classes. These requirements are specified in a number of documents, including the directive (Directive, 2006) and the standards (PN-EN ISO 11553-1, PN-EN ISO 11553-2, PN-EN 60825-1).

Identification of laser hazard and risk assessment – case studies

Two laser workplaces were selected for hazard identification and assessment: a CO₂ laser cutting station, which is used sporadically but is considered ready for use, and a fiber laser marking and engraving station, which is under construction (Furtak, 2020). Analyzing the work (Czerwińska & Pacana, 2018) in terms of selection of a method for estimating occupational risk, a risk graph (Figure 1) was selected, which estimates the expected extent of damage (S), time of exposure (E), probability of an accidental event (P), and evaluates the effectiveness of protection against the hazard (B). The method of parameter selection and interpretation is given in Table 4.

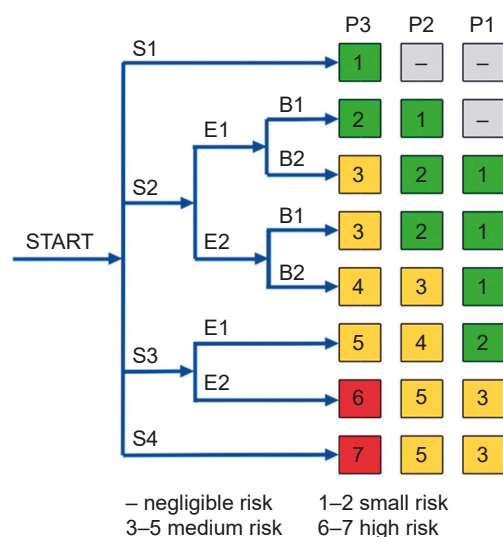


Figure 1. Procedure diagram – risk graph (Pacana, 2019)

Table 4. Parameters and evaluation criteria (Łunarski, 2006)

Evaluation parameters	Criteria
S – foreseeable extent of damage	S1 – slight injury or discomfort
	S2 – severe or irreversible injuries to one person or more
	S3 – death of not more than one person
	S4 – death of more than one person
E – duration of exposure of the worker to the hazard	E1 – rare or frequent occurrence of the hazard
	E2 – frequent to constant occurrence of the hazard
B – protection against hazards	B1 – effective when assumptions are met
	B2 – having almost no effect
P – probability of undesired event	P1 – very low probability
	P2 – low probability
	P3 – relatively high probability

Cutting station in use – laser plotter CO₂

For cutting, marking, and engraving polymers (e.g., PMMA, PE, PP, and laminates) and natural materials such as leather and wood or wood-based materials, a CO₂ laser plotter, manufactured and distributed continuously in Poland by ATM Solutions Company, is used in the studied organization. It is located in a small room and a flexible ventilation duct is connected to the plotter, which discharges exhaust fumes to a ventilation grid. The operator is equipped with goggles when performing material-cutting operations. Due to the frequent presence of persons in the room and its vicinity, an occupational risk analysis was carried out to adapt the workplace to the existing standards. It should be mentioned that it is not possible to turn the laser on without lowering the cover (Figure 2).

A checklist, shown in Table 5, was designed to identify the device features that affect the potential hazard.

The analysis of the use of the plotter and its technological capabilities, activities, and working conditions, allowed us to identify the risks listed in Table 6.

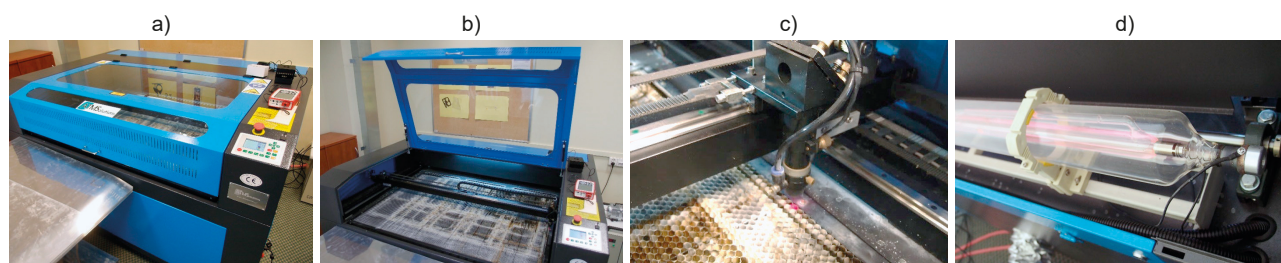


Figure 2. CO₂ laser plotter: a) general view with closed cover, b) inside after lifting the cover, c) laser head with nozzle on slides, and d) laser tube with propylene glycol

Table 5. Checklist for the workplace – CO₂ laser plotter

Hazard identification list	
Type of laser device	Laser plotter CO ₂ ATMS PRO 1390
Device	
Manufacturer	ATM Solutions, Poland
Laser type	Molecular CO ₂
Laser class	4
Wavelength	10.6 mm
Power supply	Electricity, 230 V/50 Hz
Additional laser	YES (red point)
Additional laser class	2
Labeling	YES (warning labels complying with requirements)
Beam interaction	
Nature of operation	Continuous
Pulse duration (if pulsed)	–
Laser power	150 W
Desktop height	80 mm
Direction and angle of beam	The laser beam falls in a perpendicular direction on the object in the direction from top to bottom
Working area, mm ²	1300 × 900
Workspace	Lockable, leak-proof (cover allows outside air to be drawn in)
Beam speed/frequency/nature of movement	Max speed of head – approximately 1400 mm/s Continuous travel on two axes on slideways above the worktable
Control	1. from the desktop on the device 2. software (PC + USB connection)
Variable parameters	Power, % Laser head movement speed, mm/s
Additional equipment	
Nozzle correlated with the processing head for blowing material out of the processing zone (air), compressor, liquid cooler, electric cables, and ventilation pipe	
Available personal protective equipment (PPE)	
Protective goggles	
Room	
Size	Small
Walls (color and feature)	Light beige, matt
Flooring	PVC covered with carpet
Windows (type and number)	4, double, 2 non-opening, all without beam ‘exit’ protection
Ventilation	Chimney, gravitational, ventilation riser shared with another room
Operator’s activities	
The operator places the prepared material, in the form of small pieces or sheets smaller than the dimensions of the work area, on the worktable. Turns on the device according to the manufacturer’s instructions. Activates the PC + software, defines the laser operating parameters, closes the cover, and starts the laser. When finished, opens the cover, and removes the manufactured parts.	
Materials to be processed	
Plastics: polypropylene (PP), polystyrene (PS), acrylic (PMMA)	
Substances to be processed	
The device is equipped with a glass tube filled with propylene glycol for cooling the generator	
Substances after treatment	
Solids	Waste from cut material
Liquids	–
Gases	Substances generated by the thermal action of the beam on the material (chemical compounds identified in polymer combustion)

Table 6. Risk assessment card for CO₂ laser cutting

No.	Source of danger	Hazard	Scope of damage (S)	Probability of occurrence (P)	Exposure to risk (E)	Effectiveness of protection (B)	Risk
1.	Reflected laser beam	Effects on eyes and skin	Eye, skin disease (S1)	Very low (P1)	Rare (E1)	Effective when assumptions are met (B1)	Negligible risk
2.	Electrical connections and cables	Electric shock	Burns, disability, death (S3)	Small (P2)	Rare (E1)	Effective when assumptions are met (B1)	Medium risk
3.	Hot object	Skin contact	Hand burns (S1)	Relatively high (P3)	Frequent (E2)	Effective when assumptions are met (B1)	Small risk
		Falling on the floor	Carpet melting or ignition, vapor emissions (S1)	Small (P2)	Rare (E1)	Effective when assumptions are met (B1)	Negligible risk
4.	Processing by-products	Resulting fumes	Poisoning, chronic illness or death (S3)	Relatively large (P3)	Frequent/permanent (E2)	Not effective in current state (B2)	High risk

Assumptions for B: 1 – the worker has and uses glasses; 2 – the factory connections are installed in the room by a qualified electrician; 3 – the worker (according to the instructions) after turning off the device waits for a while, the material, if it was heated, will cool down; 4 – the device is equipped with the extraction of gas products and discharge to external ventilation, but due to the leakage of the cabin and low efficiency, these gases cause an immediate danger to human health by accumulating in the processing room; in addition, the data shows that the room is relatively small, which increases the concentration of toxic substances in the workplace.

Designed fiber laser marking station

The other subject of the analysis was a stand intended for marking and engraving metals and their alloys, as well as polymers (especially in planned experimental research with stainless steels, aluminum alloys (1xxx, 2xxx, 5xxx, 7xxx), and aluminum alloys with coverings). At the initial, not completed version stage, the radiation source was manufactured in the United Kingdom by SPI Lasers, Trumpf Group, for which the tripod, power supply, software controlling the device operation, and the galvo head were designed and manufactured in Poland by DK Lasertechnik Company (Figure 3). The laser radiation originates from a solid-state source (ytterbium) and is excited in an optical fiber. The laser is cooled by air. A hazard analysis was carried out to identify the hazardous factors and to design a complete machining station.

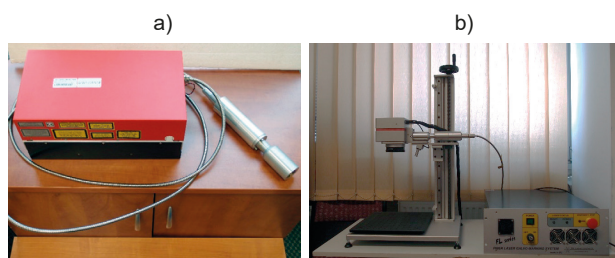


Figure 3. Fiber laser for marking and engraving: a) radiation source: generator, optical fiber, and head, and b) incomplete workplace

A designed checklist, shown in Table 7, was used to identify equipment features and planned operating conditions affecting potential hazards.

The identified hazards, when the fiber marker is operated, are given in Table 8.

Discussion of the results

In the case of CO₂ lasers, process gases emit a suffocating and unpleasant odor that causes headaches and nausea. In the context of each material to be processed, it is essential to know the type of substance emitted under heat and its effect on humans. As shown in Table 3, when cutting popular polymers on the market, polycyclic aromatic hydrocarbons, polychlorinated benzodioxins, and polychlorinated benzofurans are formed. These are very toxic compounds, causing cancer, mutagenicity, reproductive disorders, allergenicity, etc., even in very small doses. Exposure of a worker to inhalation of such substances should be treated as impermissible negligence on the part of the employer and cause for immediate preventive action. The identified possibility of ignition of the material is rather less frequent, due to the fact that the plotter is equipped with an additional nozzle with air blown into the processing zone, which is usually sufficient to extinguish the flame. The other identified hazards are not so drastic in their effects, under conditions that appropriate training is provided, the room is properly organized, supervision is implemented to create a proper work culture, and the plotter manufacturer's guidelines are followed. Legal regulations contained in directives, standards, and many publications on the safety of work with this type of equipment may prove helpful in this matter.

Table 7. Checklist for the workstation – fiber laser marking machine

Hazard identification list	
Type of laser device	Fiber laser marking machine
Device	
Manufacturer	SPI Laser, Trumpf Group, the United Kingdom
Laser type	Fiber, ytterbium
Laser class	4
Wavelength	1060 nm
Power supply	Electricity, 230 V/50 Hz
Additional laser	YES (red point)
Additional laser class	2
Labeling	YES (warning labels complying with requirements)
Beam interaction	
Nature of operation	Pulsed
Pulse duration (if pulsed)	10 ns
Laser power	20 W, single pulse energy < 2 mJ
Desktop height	Variable – mobile device
Direction and angle of beam	The laser beam falls in a perpendicular direction on the object in the top-down direction
Working area, mm ²	170 × 170
Workspace	Opened
Beam speed/frequency/nature of movement	Speed Pulse frequency kHz/scanning with hatch
Control	Software (PC + USB connection)
Variable parameters	Power, % Laser head movement speed, mm/s Pulse frequency, kHz
Additional equipment	
(lack of equipment)	
Available personal protective equipment (PPE)	
Protective goggles	
Room	
Size	Not defined – in the design phase
Walls (color and feature)	
Flooring	
Windows (type and number)	
Ventilation	In considered rooms chimney, gravitational, ventilation riser shared with another room
Operator's activities	
The operator places the prepared material, in the form of small pieces or sheets smaller than the dimensions of the work area, on the worktable. Starts the device according to the manufacturer's instructions. Starts PC + software, defines laser work parameters and starts the laser. When finished, he removes the elements from the table.	
Materials to be processed	
Stainless steels, aluminum alloys (1xxx, 2xxx, 5xxx, 7xxx), aluminum alloys with covering	
Substances to be processed	
None – ambient air cooling	
Substances after treatment	
Solids	Metal, metal alloy, and metal oxide dust
Liquids	–
Gases	Substances generated by the thermal action of the beam on the material (e.g., vapors from burnt coatings)

Table 8. Occupational risk assessment card for fiber laser marking before commissioning

No.	Source of danger	Hazard	Scope of damage (S)	Probability of occurrence (P)	Exposure to risk (E)	Effectiveness of protection (B)	Risk
1.	Reflected laser beam	Effects on eyes and skin	Eye and skin diseases (S1)	Relatively high (P3)	Frequent (E2)	In its current state, the ineffective (B2)	Small risk
2.	Electrical connections and cables	Electric shock	Burn, disability, death (S3)	Small (P2)	Rare (E1)	Effective when assumptions are met (B1)	Medium risk
3.	Hot object	Skin contact	Hand burn (S1)	Relatively high (P3)	Frequent (E2)	Effective when assumptions are met (B1)	Small risk
		Falling on the floor	Carpet melting or ignition, vapor emissions (S1)	Small (P2)	Rare (E1)	Effective when assumptions are met (B1)	Negligible risk
4.	Processing by-products	Resulting fumes	Poisoning, chronic illness or death (S3)	Relatively high (P3)	Frequent/Permanent (E2)	In its current state, the ineffective (B2)	High risk

Assumptions for B: 1 – the worker has and uses glasses; 2 – the factory connections are installed in the room by a qualified electrician.

On the other hand, when designing and commissioning a marking and engraving workplace, special consideration must be given to the emission of metal dust, alloys, and metal oxides into the air. It is necessary to purchase a filter, according to the requirements, which eliminates this factor from the environment. By inhalation, metals can cause damage to the lungs and heart, weakening of the body, problems with the digestive tract, and increases the risk of lung and liver cancer. In its present condition, the device is also not equipped with a shielding, which is the main obstacle for using the workstation. It would be advisable in this situation to determine the MDE – maximum permissible exposure – in accordance with (Directive, 2006). The shielding will not only protect the person from the radiation reflected from the surface of the workpiece, but will also create an enclosed workspace in which a filter can be positioned for safety and complete removal of dust. If it is not possible to purchase a shield, then in addition to the use of goggles, particular thought must be given to the location of the workstation in terms of the number of people in the vicinity, building elements, signage, etc., in accordance with the guidelines.

Conclusions

The availability on the market and the decreasing price, as well as the increasing quality of laser devices, make lasers increasingly more likely to be used in many industries. Although the laser as a light source is no longer a new device, laser devices, drivers, and optical components are changing with the technical progress and are adapted to the processing of new materials. For this reason, theoretically known safe working guidelines should be reviewed

and analyzed in a continuous improvement mode. The problem may be the avoidance of responsibility for toxic substances released during processing or, worse, the lack of knowledge about them and underestimation of the health problem.

The analyzed cases show that apparently trivial actions are important to eliminate unnecessary risks. Such activities include the execution of appropriate extraction ventilation with filters appropriate for the treatment, and the analysis of the instructions of the manufacturer of the equipment, which clearly state that the ventilation duct must not be connected to the ventilation grid in the room. The floor in the workplace must not be made of flammable lining, as falling hot material particles may stick to it and cause emission of toxic fumes or fire.

In rooms with lasers, which are used for research and laboratory purposes and to which members of the public, such as students, have access, there should be rules and regulations posted and applied for the use of such laboratories. This will, on the one hand, make outsiders aware of the problems of safe work, as laser radiation may be invisible, and, on the other hand, it will order the performed activities and eliminate non-compliant or dangerous activities. Due to the possibility of lack of technical documentation of the laboratory equipment, or its initial incompleteness, it is necessary to develop a stationary safe work instruction. It is also crucial to make the required markings and purchase and use eye protection equipment according to the provisions and guidelines of standards, as well as shields, sensors, signaling devices, and other safety elements, if required by the manufacturer's instructions or indicated by the conclusions of the assessment of the hazard and the situation in which the work is performed.

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The nature of the intercontinental supply chain and the building of its resilience in a company performing quality analyzes of engine oils

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Abstract

This study aims to identify a model for building a resilient supply chain in a company testing engine oil samples. Unstructured face-to-face and structured remote interviews were used as the research methods. The proposed contextual research procedure allows for the elucidation of the content of the components of the final resilient supply chain model and may facilitate theory building on the basis of future multiple case studies. As a result of the research, it was found that at the level of the described chain, its strength and continuity of flow are based on the durability of relationships with suppliers, speed, trust, and information sharing, the role of which has been explained in relation to the nature of the supply chain. Due to the nature of the chain, building its resistance on the basis of agility, which is most often indicated in model approaches, has no justification in this case. It was also established that in this process, 4.0 technologies such as the internet of things (IoT), machine learning, artificial intelligence, and cloud technologies are more important for management at the level of the entire corporation than at the level of the tested chain. The analysis covered the supply chain embedded in the industry, which (according to the author's knowledge) was not discussed in the context of logistics processes in world literature. Therefore, the results of the work undertaken are of great cognitive value.

Introduction

Taking into account the dominant research topics over the last three decades in the field of the supply chain, it can be concluded that they mainly relate to inventories (1990–1999), cost aspects (2000–2014), sustainability (2015–2019) and, currently, digitization (Maryniak et al., 2020). The topic of chain resilience appears in the context of eliminating disruptions in flows and determining the appropriate level of inventory, risk management, the issue of costs of lost benefits and penalties related to non-delivery,

and the use of 4.0 technology to strengthen the chain or in the context of showing the relationship of resistance to the chain sustainable and green issues. Due to recent events related to the pandemic, the war in Ukraine, and the unstable geopolitical situation, as well as due to strategic changes in supply chains, this topic is gaining importance and, thus, becoming an increasingly interesting and needed research field. Based on the review of the SCR definition (Orlando et al., 2022), it can be concluded that resilience refers to the phase of preparation before disruptions, the response to them, and the ability to find oneself

in the new economic reality. This study assumes that the resistant chain is a chain that, as a result of disturbances of internal or external factors, can quickly reach the starting position or change it (through location and product configuration, relationships with contractors, and internal reorganization) so that it does not disturb the essential ways of business continuity. It is, therefore, a certain ability to resist shocks occurring in the supply chain. Hence, it is important to show how companies cope with this challenge. Models and research frameworks for resistant chains are discussed in the literature on the subject (Table 1).

Some authors have discussed the factors that determine their vulnerability, while others point to eliminating disturbances. Regardless of the nomenclature, the present authors try to identify lists of resistance-supporting elements or lists of constructs/

Table 1. Factors that make up the model of building resilience supply chain – literature not present in the previous review lists

Number of factors	Type of research	Authors
6	empirical	Tasnim, Z., Shareef, M.A., Dwivedi, Y.K. et al. (2022)
3	empirical	Iftikhar, A., Purvis, L., Giannoccaro, I. et al. (2022)
15	empirical	Baig, M.M.U., Ali, Y. & Rehman, O.U. (2022)
7	empirical	Ozdemir, D., Sharma, M., Dhir, A. et al. (2022)
10	empirical	Kaur, H. & Singh, S.P. (2022)
4	empirical	Queiroz, M.M., Wamba, S.F., Jabbour, C.J.C. et al. (2022)
4	empirical	Wang, J. & Zhao, C. (2022)
2	empirical	Orlando, B., Tortora, D., Pezzi, A. et al. (2022)
13	literature review	Maharjan, R. & Kato, H. (2022)
2	empirical	Irfan, I., Sumbal, M.S.U.K., Khurshid, F. et al. (2022)
2	empirical	Bag, S., Rahman, M.S. Srivastava, G. et al. (2022)
3	theoretical	Ramachandran, S. & Balasubramanian, G. (2022)
12	empirical	Zamiela, C., Hossain, N.U.I. & Jaradat, R. (2022)
4	empirical	Yazdanparast, R., Jolai, F. & Pishvae, M.S. et al. (2022)
11	empirical	Das, D., Datta, A., Kumar, P., Kazancoglu, Y. et al. (2022)
6	literature review	Bechtsis, D., Tsolakis, N., Iakovou, E. et al. (2022)

elements decomposed into detailed parts. These elements are examined by indicating their importance in the hierarchy or by showing the strength of their relationship. Among others, Tasnim et al. (Tasnim et al., 2021) proposed a model for supporting the resilience of the tourism supply chain, which consists of six modules. Baig et al. (Baig, Ali & Rehman, 2022) examined the importance of fifteen elements in the oil supply chain. Ozdemir et al. (Ozdemir et al., 2022) focused on the velocity epicenter of retail supply chain resilience and studied seven constructs. Queiroz et al. (Queiroz et al., 2022) studied the resistance of chains embedded in several different industries using four constructs. In turn, Iftikhar et al. (Iftikhar et al., 2022) also tested resistance on the basis of various industries using three constructs. Wang and Zhao (Wang & Zhao, 2022) considered four constructs, additionally linking this issue with carbon footprint reduction. Kaur and Singh (Kaur & Singh, 2022) distinguished ten elements in relation to the humanitarian supply chain. Orlando et al. (Orlando et al., 2022) examined two constructs dividing entities into those dealing with the flow of medical goods related to the pandemic and the trade in other goods. Research proposals from earlier years were included, *inter alia*, in the review articles by Karl et al. (Karl et al., 2018), Maharjan and Kato (Maharjan & Kato, 2022), and Maryniak et al. (Maryniak, Bulhakova & Lewoniewski, 2021).

Material and methods

Due to the fact that the supply chains of individual enterprises are specific, and their examination is multi-faceted, the use of qualitative methods in relation to them is justified. Based on bibliometric research on supply chain research methods, it is stated that 65% of the works concern this type of procedure (Abbasi & Mohamadi, 2022). In the presented study, a case study was used, which is employed in a quarter of works in the field of the supply chain, and it is the second most common method used after mathematical modeling. The research subject is specific because it belongs to a global corporation, serves clients from many continents, is the only company stationed in Europe and, at the same time, is a small entity where the flow supervision is not assigned to a logistics unit consisting of many people. This solution works efficiently because the general flow procedures are developed at the corporate level, and the operational sphere is organized and controlled at the level of the audited unit. The study adopted a five-stage research procedure for

case studies proposed by Stuart et al. (Stuart et al., 2002) and took into account comments directed to each of the stages (Koulikoff-Souvireon & Harrison, 2005). The *a-priori* study identified constructs from the literature that helped to better embed the theoretical framework of the study.

Since the knowledge of the creation of resistant chains is only in the development phase, the research considered a wide range of factors that may affect the constitution of resistance to arbitrarily assess their suitability in a given case. Therefore, a research question was formulated “Which of the elements supporting the building of resilient chains are adequate for the examined enterprise?” Simultaneously, it is noted that certain elements such as agility and transparency appear much more often in research models. Therefore, it is important to answer the question: “Does the popularity of a given construct in research models determine its driving force in the creation of resistant chains?” In the second step, a supply chain was selected for the research, which is not described in the literature, to enable an increase in the cognitive value of the presented material. A case was selected that may be a potential source of questioning popular statements appearing in the theoretical layer. This is one of the basic approaches in selecting case studies. Little is known about the methods used to create robust chains; therefore, the data collection method made it possible to understand:

- the context of strategic and operational conditions in which resilience is built,
- why the identified constructs might be important.

The need to show the context of the activities makes it impossible to perform multiple case studies in one study. Therefore, in the future, it is justifiable to repeat the research in order to create a series of multiple case studies and better substantiate the conclusions drawn. In the third step, data was collected on the basis of data provided openly by the company and data collected through contact with the company. Three times individual in-depth interviews (IDIs) were used as the basic research method. The first two interviews were designed to gather information about the company’s supply chain and disruptions in flows. In the second interview, some threads were clarified. In the third interview, they were asked to rank the factors that influence building the resilience of the supply chain according to the given scale. The first two interviews consisted of direct contact with the company and were in an unstructured form, while the collection of data using a structured survey questionnaire took place through remote communication using the Microsoft Teams platform.

Qualitative bibliometric studies were conducted to identify the elements constituting the resistant chain models (Booth et al., 2021). Systematized elements from the perspective of the existing research models (Maryniak, Bulhakova & Lewoniewski, 2021) were used to evaluate them at the level of the discussed case study. A total of 20 test items were assessed.

The contact person for the transmission of information was the company manager, who is responsible for contacts with other actors in the supply chain and with companies located around the world. Simultaneously, the manager had the opportunity to collect information from other employees in order to provide reliable answers. In total, the data collection on the side of the researchers lasted several hours over three meetings. To exclude biased judgments and to ensure the quality of the information collected, it was not stated before the study which of the test items were mentioned more often in the research models, and they were asked to explain the causal relationships regarding the answer given in the context of the information obtained about the nature of the organization. In the fourth stage, we cleaned up the data from the side threads that appeared during the interview and focused on a limited set of data that illustrated the context and rationale for selecting the elements that make up the resistant chain. The purpose of this stage was to understand contextual data and explain and interpret the phenomenon under study. In the last stage, an attempt was made to critically assess whether the relations between the cause and the selection of the model were properly established, and a theoretical replication was performed, i.e., based on a broader theory. It was shown that obtaining different results than previously conducted is rational.

Characteristics of the research subject

Based on the interviews, it was found that the subject of the research is the supply chain of a company, which carries out qualitative analyzes of engine oils, cooling fluids, and fuels that are necessary for the proper operation of, for example, gas engines powering electric turbines, wind turbines, hydraulic transmissions, etc. The main goal of the company is to improve the reliability of machines. The company has been operating since 2014, with foreign capital and a flat organizational structure. The company has been an integral part of a global corporation that has operated since 1999. The entities are related to the network in terms of capital and finances. All laboratories are linked to the headquarters. Budgets, financial

statements, expenses for laboratory equipment, and other fixed assets must also be accepted by the head office. The corporation has seven global laboratories worldwide: in South America, Central America, North America, and Europe. The audited entity is the only entity located in Europe – in Poland. Due to the synchronization of information and logistics flow, 165,000 customers worldwide are served. The processes are unified based on the American Society for Testing and Materials (ASTM) standards. Materials for testing are transferred between units located on different continents, while on the plane of the flow of auxiliary, non-commercial materials – each unit performs independent logistics services. The units are equipped with the same equipment (apparatus). This allows a significant reduction in the cost of consumables. In addition, laboratory analyses performed on the same equipment enable the results to be compared between all laboratories. This is of particular importance in today's age of globalization. Customers who are largely global concerns, such as Chevron, Shell, and Mobil, are present on all continents and, therefore, the results prepared for them must always be comparable.

In particular, the audited company, the branch of which is located in Poland, is engaged in the activities of: physicochemical analysis of industrial oils (i.e., hydraulic, gears, and engines, etc.); physicochemical analysis, i.e., the determination of the amount of wear metals in the oil, precise determination of the water content, soot content, examination of the amount, and size of solid particles (also known as impurities), and consultancy aimed at extending the failure-free operation of machines and the related cost reduction. The company contributes to extending the life cycle of assets and minimizing the costs of repair and replacement due to the possibility of predicting the date of necessary equipment maintenance. The company's network is located in Greater Poland and in foreign partner location points. The supply chain is especially developed at the exit. At the corporate level, the target customers are located in over 90 countries, while the European branch serves customers from Europe, North Africa, and Asia. The vast majority – around 85% of the samples – originate from customers based in the European Union. The remaining 15% of samples were supplied from customers in Africa (11%) and Asia (4%). As much as 95% of the created samples are sold on the foreign market, which requires the implementation of efficient distribution logistics in international supply chains. All samples are shipped by air freight for all countries (except for local, Polish customers).

In this case, the delivery is made by courier companies. Air transport is the most expensive but at the same time the fastest, which guarantees customers almost immediate access to the results and parameters of a given oil.

Samples and parts of the apparatus are moved within European or intercontinental chains, while reagents and small equipment originate from regional entities. The reagents are mainly purchased from distributors of renowned world producers, such as Merck, VWR, and Sigma-Aldrich. It is necessary because the laboratory has ISO17025 accreditation, i.e., a system for unifying technical and quality management requirements for the research laboratories. Other accessories, such as pipettes, glass, and sorbets, are purchased in commercial units. Deliveries of samples are carried out, in 45% of the cases, from entities taking the role of intermediaries in the supply channel (in terms of the number of samples) and directly from customers for 55% of the time. In Europe, there are three small logistics centers located in Germany, Belgium, and the United Kingdom, to which samples from smaller customers are shipped. Each point acts as a separate company. The largest customers send samples directly to the laboratory in Poland.

Based on the conducted interviews, it can be concluded that: the configuration of the analyzed supply chain is based on external infrastructure (i.e., transport, warehouse, and office); the complexity of the input supply chain, measured by the number of direct suppliers, is much smaller compared to the output chain structure; the input and output chain is short taking into account the number of links, because in the majority of logistics operations the company contacts the producers of purchased materials and end customers; most of the logistics operations on the entry and exit sides are intercontinental in nature; and in some European countries, the consolidation of the cargo (samples) takes place, which is performed by an external entity and then the material is transported to the unit located in Poland. Since 2014, the volume of products moved has increased, while supply chains have lengthened only slightly.

There was also a slight geographic diversification. Based on the information obtained, it can be concluded that increasingly more customers are sending samples from outside the European Union. This is because the main emphasis is on the development of Asian clients and clients from the Persian Gulf region. There is also a noticeable increase in the chain complexity resulting from the rise in the number of final recipients who are also the ordering parties. The company reaches increasingly more

customers. In the case of large corporations, the involvement of intermediary companies is not justified, as each large company has its own specific requirements that must be considered when performing laboratory tests.

Detailed flow paths in the characterized supply chain include (Figure 1):

initial flows

1. USA – Poland: plastic bags and bottles (from corporate headquarters).

basic domestic flows

2. Poland (Poznań): cartons, work clothing, and labels.
3. Poland (Warsaw) – Poland (Poznań): pipette, gloves, and spare parts used for the diagnostic equipment [5%].
3. Poland (Warsaw) – Poland (Poznań).
4. Poland (Kędzierzyn Koźle and Tarnowo Podgórne) – Poland (Poznań): solvents.
5. Poland (Tarnowo Podgórne) – Poland (Poznań): office articles.
6. Poland (Zielona Góra) – Poland (Poznań): sorbents.
7. Poland (Gliwice) – Poland (Poznań): reagents [20%].

basic international flows

8. Germany – Poland (Poznań): sample tubes.
9. Asia – Poland (Poznań): laboratory glassware and reagents (e.g., China and Taiwan) [80%].
10. USA – Poland (Poznań): diagnostic equipment and spare parts used for the diagnostic equipment [95%].

reverse flows

11. Poland (Toruń) – Poland (Poznań): post-test reagents, used sorbents, and used bottles.
12. Poland (Sieradz) – Poland (Poznań): used oils.

warehouses – the place of receipt of samples from only one country.

13. Germany, Belgium, and the UK.

customers in various locations

- Poland to customers: plastic bags, bottles, and cartons;
- customers to Poland: Europe [85%], for example, Spain, Italy, Portugal, Estonia, Lithuania, and Latvia; other locations, for example, Asia and Africa [15%].

Results and discussion – the ways to build resilience in supply chains

To diagnose which elements of the supply chain are used to build chain resilience, twenty elements selected on the basis of an extensive review of the research models presented so far (Maryniak, Bulhakova & Lewoniewski, 2021) were assessed. A seven-point Likert scale was used to rank the answers, in which 1 is very significant and 7 is definitely irrelevant (Figure 2).

Due to high costs and extended usability, the purchase of test equipment is made every few years; therefore, it is not a subject of current logistics. Among the fixed assets, the company's equipment includes mainly research machines that require periodic replenishment of parts. Due to the high costs of this type of investment, the acquired basic devices are not purchased on the primary market. At the entrance – in addition to the samples received from customers and intermediaries – the supply chain is supplied with materials and the aforementioned non-commercial materials such as reagents, small equipment (pipettes and laboratory glassware), gloves, oil-absorbing mats, and workwear. The purchase

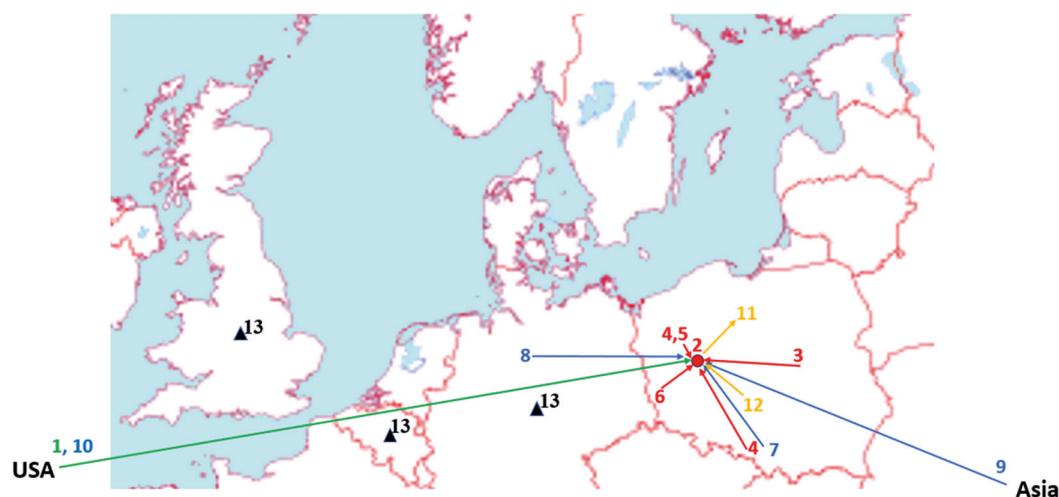


Figure 1. The supply chain of an oil testing company

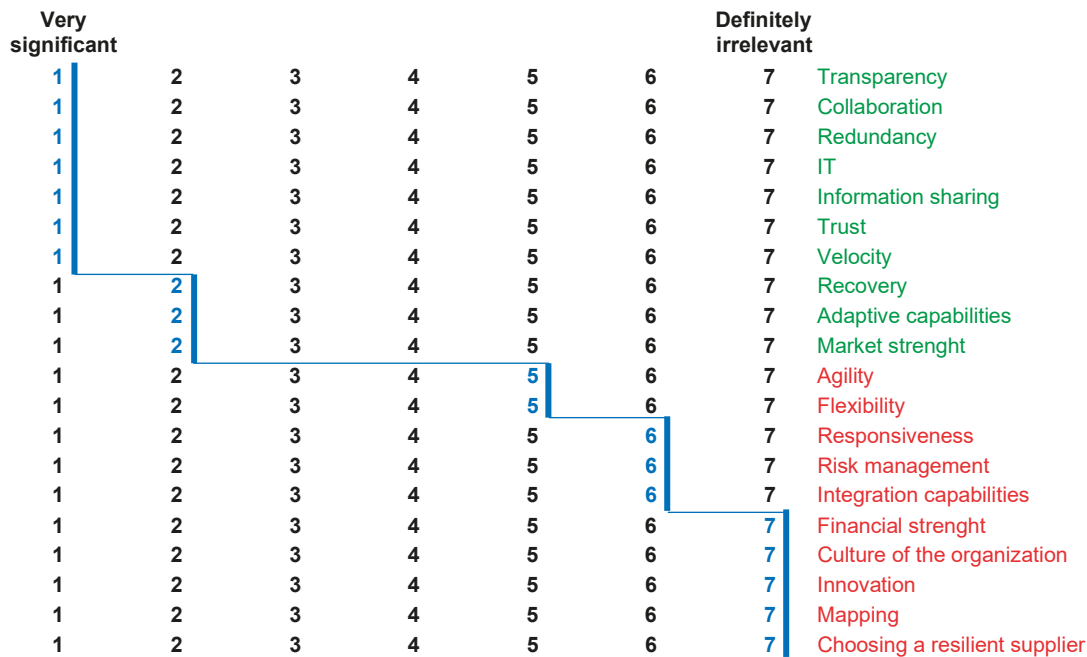


Figure 2. Factors that make up the model of building resilience in the examined enterprise

of auxiliary materials depends on the number of orders; however, a critical, necessary inventory level is maintained. The length of the channel supply for the materials in question ranges from 200 to 400 km, and it is mostly of a regional nature. The number of vendors does not change as they are accredited vendors. Due to the quality of the services provided, the analyzed entity concludes contracts with suppliers who guarantee the delivery of certified products. The materials are supplied by final producers or are purchased from the distributors.

In day-to-day work, disruptions are caused by the failure rate of machines that are not related to their efficiency but result from a high turnover of employees. Operating the equipment requires several months of training; therefore, it is a significant problem that requires a solution in the future. During the pandemic, there were additional logistical problems with the supply of reagents, machine components, and the availability of auxiliary equipment. This forced an increase in the level of inventories and, thus, built a kind of redundancy to ensure the continuity of laboratory tests and the adopted time regime. Due to the complexity of the equipment, and the fact that (in most cases) the elements are imported from abroad, the waiting time for spare parts has been extended. Ultimately, it increased the storage costs. However, no correlation was found between the pandemic and the number of orders.

Continuity of flow is ensured thanks to the trust and long-term relationships which, due to formal reasons and to the specificity of contacts and delivered

materials, cannot be replaced with other dynamic relationships. The durability of the chain is a result of long-term contracts with suppliers, on the basis of which the trust and quality of the analyzes are developed; high transaction costs of a possible change of supplier; no need to multiply supply and distribution channels and adapt to current fashions and trends, such as in the case of the clothing chain or innovative products. In the event of disruptions related to, for example, equipment failure or deliveries of test components, the company tries to restore resources or flows according to the same operating patterns in the shortest possible time. This is, on the one hand, due to the nature of the links in the supply chain and, on the other hand, to the declared level of service. Speed is, therefore, the asset on which the company bases its strength. Hence, the company guarantees a very short time, i.e., 48 hours, to analyze the sent samples.

The company also cares about uninterrupted and constant access to information. This is accomplished by using high-class IT systems. After sending the oil for testing, detailed data on its parameters, type of device, operation of the device it is used for, etc. are entered. At the time of delivery of such a sample to the laboratory, the QR code is scanned. The Horizon system allows all customers to log samples online, and the same system will enable clients to access reports. All the data on the number of registered samples, the number of orders, the number of customer orders, and the number of performed and completed tests are visible in real-time. This data is available for every laboratory that is part of the

corporation. The company provides IT support solutions in the field of integration of sample data with the laboratory. It manages laboratory equipment through the CMMS system and performs periodic inspections and calibration. Through the EAM system, it archives data on the maintenance of devices in operation and forecasts how the parameters of materials may change, and with what frequency they need to be tested.

The entire service system is, therefore, extremely transparent. It also manifests itself in the system of building relationships with customers who remotely share data on the operation of machines and can count on online assistance in the event of a failure. Only as a last resort is a service technician required. Usually, it concerns very expensive machines, the breakdown of which, for example, due to faulty oil parameters, would cause huge losses or even bankruptcy of the company. Therefore, building efficient samples and information flows must be embedded in deep and mutual trust. The adopted resilience model based on cooperation, redundancy, transparency, information sharing, trust, and speed is only partially consistent with the models proposed in the literature on the subject. For example, from the model of Belhadi et al. (Belhadi et al., 2021), resilience is influenced by collaboration. According to Mohammed and co-authors (Mohammed et al., 2021), it is affected by trust and information sharing and, from the study by Johnson, Elliott, and Drake (Johnson, Elliott & Drake, 2013), the speed of the operation is also important. However, in model terms, it is most often emphasized that agility and flexibility are the key factors in the construction of resistant chains (Christopher & Peck, 2004; Brusset & Teller, 2017; Cui, Idota & Ota, 2019; Mohammed, 2020). It is especially visible in the reviews, which list the individual constructs that make up the research models (Maryniak, Bulhakova & Lewoniewski, 2021). Considering the characteristics of the described supply chain, it can be stated, however, that the obtained results are rational and contextually justified.

Conclusions

The study shows the specifics of the supply chain, which was discussed for the first time in the scientific literature. Its nature justifies the adopted model of resistance. It differs from the classic approach, in which agility is most often indicated as the basis for eliminating disturbances. In the analyzed chain, the ability to adapt to changing market needs is of secondary importance, as agility and flexibility were

assessed as rather insignificant, and sensitivity is also insignificant. Moreover, risk management, ability to integrate, financial strength, organizational culture, innovation, process mapping, and the selection of resilient suppliers turned out to be irrelevant or definitely irrelevant factors. The model specific to the examined enterprise is a system in which transparency and information sharing play an important role. Therefore, it is clearly a communicative model in which efficient IT systems are used to transfer information, perform tasks quickly, and can recreate resources that are largely immaterial. It is also a model in which potential disruptions in the flow of material resources are eliminated through redundancy. It is a unit that builds its strength on the basis of brand strength, trust, cooperation, loyalty, partners' reliability, and lasting relationships on the side of deliveries, key customers, and the development of permanent procedures. Based on the research, it has been proven that the popularity of the occurrence of a given construct in research models does not determine its causative power in the creation of resistant chains. That is why it is important for science and economic practice to show various ways of achieving the durability of chains, including those that differ from popular patterns.

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Energy and labor intensity of manufacturing processes progressing toward sustainable development: A systematic literature review and SWOT analysis for a steel manufacturing company

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JEL Classification: L60, O14, Q01

Abstract

Manufacturing, as one of the main pillars of a civilized lifestyle, will be strongly affected by sustainability issues, and it will play an important role in establishing a sustainable future. Within the area of sustainability issues, some specific issues are pointed out, such as the energy and labor intensity of manufacturing processes. The main aims of this paper are a systematic literature review and the evaluation of the energy and labor intensity of manufacturing processes in an industrial enterprise while proposing changes toward sustainable development. In the research, 163 scientific publications (77 related to China) were taken from the Web of Science (WoS) database based on selected keywords describing the studied phenomenon. The analyzed publications were divided into five areas (clusters). In terms of evaluating the energy and labor intensity of manufacturing processes, twelve production processes were selected, which were then grouped according to their most important areas of similarity (automation, ergonomics, and discomfort). The systematic literature review was carried out using the VOSviewer software, version 1.6.14. This article also uses the methodology of a case study with a simplified SWOT analysis based on interviews with employees and expert panels. The subject of the research is an industrial enterprise representing the steel manufacturing sector in Poland.

Introduction

Manufacturing, as one of the main pillars of a civilized lifestyle, will be strongly affected by sustainability issues, and it will play an important role in establishing a sustainable future. Today, nearly all manufacturing models are based on the old paradigm. Technology, on which manufacturing is largely based, is asked, together with culture and the economy, to devise tools and options for building new solutions toward a sustainable manufacturing concept. Generally speaking, new technology, business, and lifestyle models will be the

cornerstones of the new sustainable world, and this will be particularly true for the manufacturing sector (Garetti & Taisch, 2012). Globally, the manufacturing sector is a major contributor to economic expansion and improvement in the standard of living. However, manufacturing processes have negative impacts on the environment and society as they consume excessive scarce resources and produce hazardous wastes and emissions (Saad, 2018). Manufacturing companies are facing the need to adopt new strategies, such as sustainability so that they can respond to the market and customer's demand for sustainable products due to the scarcity

of natural resources or government policies (Eslami et al. 2019).

Within the area of sustainability issues, this paper focuses on some specific issues, such as the energy and labor intensity of manufacturing processes. Economic growth is often associated with high energy consumption, and energy intensity may bring about and exacerbate a variety of negative external production impacts, including environmental pollution and global warming, which has become a principal threat to sustainable development (Wang, Lee & Li, 2022, Luken & Castellanos-Sil, 2011). The literature in the field of energy economics has proposed some factors affecting energy intensity (Wang, Lee & Li, 2022), e.g., per capita income (Jimenez & Mercado, 2014; Agovino, Bartoletto & Garofalo, 2019), technological innovation (Wurlod & Noailly, 2018), urbanization (Farajzadeh & Nematollahi, 2018), trade openness (Rafiq, Salim & Nielsen, 2016), financial development (Pan et al., 2019), and energy prices (Karimu et al., 2017; Tajudeen, 2021).

When it comes to labor intensity, post-growth economists propose structural changes toward labor-intensive services, such as care or education, to make the economy more sustainable by providing meaningful work and reducing the environmentally damaging production of material goods (Hardt et al., 2020). Hami et al. (Hami, Muhamad & Ebrahim, 2015) wrote that companies need to re-establish their corporate strategy by introducing and implementing more integrated sustainable practices. Prior researchers believed that sustainable manufacturing practice (SMP), defined as a firm's intra- and inter-organizational practices that integrate environmental, economic, and social aspects into operational and business activities, would lead to better firm performance. Due to regulatory and market pressures, large-sized manufacturing enterprises have started reporting their sustainability efforts as per established guidelines. Small and medium-sized enterprises (SMEs), on the other hand, play an even greater role in optimizing the economic structure and social stability of developed and developing economies. Ironically, they struggle more to expand and to communicate their sustainability efforts to their stakeholders (Prashar, 2019).

Taking into consideration the above, work on implementing sustainability principles and procedures in manufacturing companies is still needed to achieve Sustainable Development Goals (SDGs). Thus, the content of this article is dictated by the research plan that is part of the implementation doctorate titled "Creating innovation and sustainability

of the company with the use of multi-criteria decision support methods." To develop the decision-making model, the author defined three decision-making areas concerning:

1. The assessment of individual product groups in terms of the effectiveness of the use of raw materials and waste management.
2. Optimization of the production process in terms of energy and labor consumption.
3. The assessment of suppliers in the company's sustainable supply chain.

This paper analyzes the second area. The author analyzes the topic of optimization of the production process in terms of energy and labor consumption toward sustainable development from two points of view:

- bibliographic analysis;
- simplified SWOT analysis in the industrial enterprise that was the subject of the implementation doctorate.

Therefore, the main aims of this paper are a systematic review of the literature in the context of the occurrence of keywords relating to the energy and labor intensity of manufacturing processes and sustainable development in the English-language literature and the evaluation of these processes in an industrial enterprise, while proposing changes toward sustainable development.

The research questions regarding the systematic literature review concern:

- finding out how often the indicated keywords are cited, collectively and considered separately?
- how is research on this subject divided into research areas (so-called clusters)?

The SWOT analysis involved finding the answers to the following questions:

- what are the groups of production processes that should be analyzed regarding the energy and labor intensity of manufacturing processes?
- what are the strengths, weaknesses, opportunities, and threats for these processes with regard to sustainable development?
- what should be the directions toward sustainable development for the analyzed enterprise?

It should be noted that this manuscript identifies elements of the manufacturing process connected with sustainability with a focus on environmental issues. Societal and economic issues regarding sustainability are indeed equally crucial but are outside the scope of this manuscript. Also, in the case of the optimization of the production process in terms of energy and labor intensity, energy intensity was treated as electricity or heat consumption,

considering recovery and losses, and the workload was assessed from the perspectives of discomfort, risk, and negative factors (especially in terms of the ergonomics of workplaces and occupational health and safety). The subject of the research is one of the well-established industrial enterprises representing the steel manufacturing sector in the West Pomerania region in Poland.

Systematic literature review – the methodology and results

The research procedure used in this study included several stages. In the first of them, 163 scientific publications were taken from the Web of Science (WoS) database based on selected keywords describing the studied phenomenon. Table 1 shows the results of the WoS database search. Studies in which the title, abstract, or keywords contained references to the terms energy intensity, labor intensity, manufacture, and sustainability were considered.

In the set of data separated in this way, the most frequently repeated terms appearing in the titles of abstracts and keywords indicated by the authors of the researched studies were searched for. VOSviewer software, version 1.6.18 was used to identify them. Figure 1 shows the connections between the identified keywords (those with at least six co-citations were considered) that formed five clusters.

In the first cluster (red), connections between the following keywords were identified: emissions (carbon-dioxide, CO₂, greenhouse-gas), decomposition analysis, driving forces, economic growth, energy policy, energy consumption, lmdi.

The second cluster (green) describes the connections between such terms as: decomposition and divisia index, drivers, efficiency, emissions, intensity, manufacturing sector, and policy.

The third cluster (blue) was created by the connections between the terms concerning: energy consumption, manufacturing, sector, productivity, and sustainable development.

Table 1. The results of the research provided on the basis of the publications indexed in the WoS according to the selected keywords (the author's elaboration based on WoS database)

The combinations of topics	Number of papers
"labour intensity" AND manufactur* AND sustainab*	7
"energy intensity" AND manufactur* AND sustainab*	157
"labour intensity" AND manufactur* AND sustainab* OR "energy intensity" AND manufactur* AND sustainab*	163

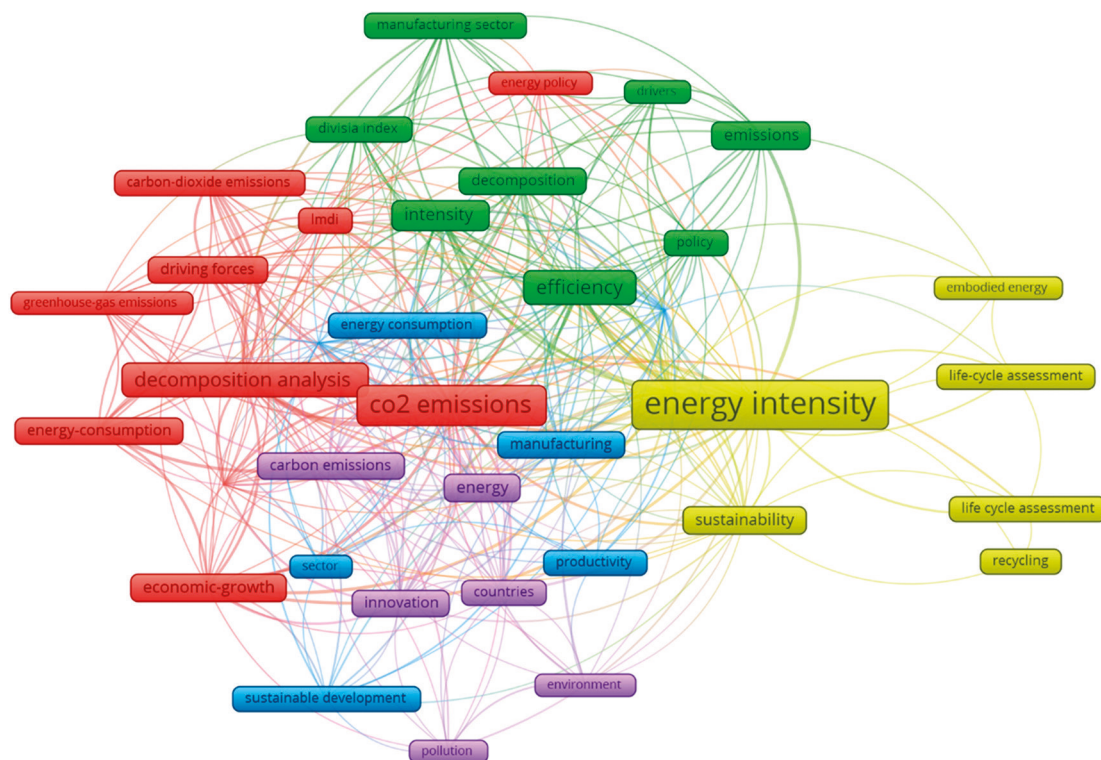


Figure 1. Clusters network (the author's elaboration in VOSviewer software)

In the fourth cluster (yellow), the key elements are the connections between the terms: energy intensity and such words as: embodied energy, life cycle assessment, recycling, and sustainability.

The fifth cluster (purple) describes the connections between the words: carbon emissions, countries, energy, environment, innovation, and pollution.

It is worth noting that in the selected clusters, terms referring to energy use and the adverse environmental impact associated with various types of emissions, such as CO₂, greenhouse gases, etc. dominate.

Among the publications that deal with this type of issue, one can mention, for example, papers by the following authors: Chontanawat et al. (Chontanawat, Wiboonchutikula, & Buddhivanich, 2014), El Anshasy and Katsaiti (El Anshasy & Katsaiti, 2015; 2016; 2018), Torrie et al. (Torrie, Stone & Layzell, 2016), Kim (Kim, 2017), Pardo Martinez and Silveira (Pardo Martinez & Silveira, 2013), and Zhang et al. (Zhang et al., 2019).

There are also many studies in which attempts have been made to identify various types of factors determining the intensity of energy use, including analyses involving the decomposition of such use into its constituent parts. Such analyses have been presented in the following studies: Anctil et al. (Anctil et al., 2011), Sorrell et al. (Sorrell et al., 2012), Ma et al. (Ma, Wang, & Chen, 2013) and Cheb and Liu (Chen & Liu, 2021).

The created database of 163 scientific papers was used in the next stage of the study to identify papers in which there were simultaneous references to a greater number of duplicate keywords. After reviewing the collected studies (their titles, keywords, and abstracts), it was found that there were many of them that described the results of the analyses in terms of particular geographical regions; these were also studies focused on identifying factors that determine outcomes, such as the level of unfavorable emissions and the effectiveness of the technologies used, while also referring to sustainable development. This information was used to build the following six binary variables with two categories of “yes” and “no”, which were most often repeated in the studied publications:

- X_1 – region (1, if the information described in the paper was presented in terms of regions, including a combination of several countries in a given geographical region; 0, in the other case);
- X_2 – country (1, if the research results presented in the study were analyzed at a higher aggregation level than the region; it could refer to individual

countries as well as continents, such as Europe or Asia, or groups of countries, e.g., the European Union; 0, in the other case);

- X_3 – factor (1, if the study analyzed the various factors, drivers, or determinants most often determining the intensity of energy use; 0, in the other case);
- X_4 – decomposition (1, if in the discussed considerations the decomposition method was used, including the use of, for example, the Divisia Index; 0, in the other case);
- X_5 – sustainable development (1, if direct references to sustainable development were identified in the analyzed studies, i.e., those in which sustainable development was an important element of the study; 0, in the other case);
- X_6 – emission (1, if the analyzed studies references to various negative effects related to human activity; 0, in the other case).

Table 2 presents information on the number of papers containing the indicated individual keywords.

Table 2. The results of the identification of the number of papers containing the analyzed keywords

Keywords	Number of papers
region	39
country (China)	105 (77)
factor	64
decomposition	57
sustainable development	80
emission	83

The review of publications indexed in the WoS database shows that out of 163 papers, 39 concerned analyses carried out at the regional level. Examples of these were studies by such authors as:

- El Anshasy and Katsaiti (El Anshasy & Katsaiti, 2015), investigated the causes of unsustainable growth in energy consumption and environmental degradation in the six Gulf Cooperation Council (GCC) countries. This study analyzed the long-term relationship between per capita CO₂ emissions and energy intensity in the GCC;
- Haukioja et al. (Haukioja et al., 2018), constructed smart specialization indicators for LAU-1 regions in Finland, i.e., for the 70 Local Administrative Unit level 1 (LAU-1) sub-regions in Finland. In the study, the authors used three smart specialization indicators: the Herfindahl-Hirschman Index for regional resilience (HHI), the regional relative specialization index (RRSI) based on the Balassa-Hoover Index (B-H), and the relative

employment volume index in the manufacturing sector (LIMI);

- Tavakoli et al. (Tavakoli et al., 2016), presented a top-down model of equity for the allocation of GHGs emission (such as GERA) for Iran, but at a provincial level.

A total of 77 papers about China have been identified. However, studies on energy use, energy efficiency, and the effects of energy consumption on the environment, where mainly various negative aspects related to the emission of substances harmful to human health were described, were presented in as many as 83 papers, among them papers by authors such as Li (Li, 2022), Azhgaliyeva et al., (Azhgaliyeva, Kapoor, & Liu, 2020), and Zhang et al. (Zhang et al., 2019).

The list of papers in which connections between the words sustainable development and emission were identified (Table 3) is interesting. Such connections were identified in 52 studies by authors such as Savona and Ciarli (Savona & Ciarli, 2019), Zhang et al. (Zhang et al., 2019), Azhgaliyeva et al. (Azhgaliyeva, Kapoor, & Liu, 2020), and Yu et al. (Yu et al., 2021).

Table 3. Cross-tabulation for variables: sustainable development and emission

Sustainable development	Emission		Summary
	Yes	No	
Yes	52	28	80
No	31	52	83
Summary	83	80	163

It is also worth paying attention to the relationships between the terms factor (driver) and decomposition. Table 4 shows the distribution of studies that include these types of keywords in the prepared database.

Table 4. Cross-tabulation for variables: factor and decomposition

Factor	Decomposition		Summary
	Yes	No	
Yes	40	24	64
No	17	82	99
Summary	57	106	163

As can be seen from the presented list, in 40 out of 163 analyzed publications there were simultaneous references to the indicated terms. Among them were the studies: Lin and Du (Lin & Du, 2014),

Dehning et al. (Dehning et al., 2017), Zhang et al. (Zhang et al., 2019), and Dolge and Blumberga (Dolge & Blumberga, 2021). These were publications important for the analyzed research topic. They most often presented the results of research conducted with the use of advanced statistical and mathematical models.

Dehning et al. (Dehning et al., 2017) used a multiple regression model to determine the factors influencing the energy consumption of automotive plants. In turn, Lin and Du (Lin & Du, 2014) used two methods to identify and quantify the driving forces behind changes in energy intensity in Chinese provinces in 2005–2010, combining index decomposition analysis (IDA) and production-theoretical decomposition analysis (PDA). On the other hand, Zhang et al. (Zhang et al., 2019) used the Multiplicative Logarithmic Mean Divisia Index II (M-LMDI-II) method to analyze the factors influencing energy intensity changes in China's Shanxi Province. Yet another approach was used by Dolge and Blumberga (Dolge & Blumberga, 2021), who used the log-Mean Divisia Index (LMDI) distribution analysis to investigate how industrial energy-related CO₂ emissions in Latvia changed in 1995–2019. In the developed model, they considered five factors, including the effects of industrial activity, structural change, energy intensity, fuel mix, and emission intensity.

SWOT analysis for the steel manufacturing company

This research concerns a case study of one of the steel manufacturing companies in the West Pomerania region in Poland. The profile of the analyzed company is mainly subsidiary industrial production of metal structure components, prefabricated for external partners, according to their requirements and specifications.

One of the objectives of the implementation doctorate was to optimize the production process in terms of energy and labor intensity (consumption), where energy consumption was treated as electricity or heat consumption, considering recovery and losses, and the workload was assessed from the perspective of discomfort, risk, and negative factors (especially in terms of ergonomics, workplaces, and occupational health and safety).

To achieve this goal, the first step was to analyze the company's existing situation in the context of the analyzed issues. The author (a Ph.D. student) together with the Maintenance Manager conducted an inventory of all machines, devices, and production

facilities, along with their electricity consumption and possible heat generation. The machines and devices, as well as objects related to individual technological processes, were listed in an ERP system. Under the supervision of the doctoral student, an **expert panel was established**, which included the Heads of Production Departments and the Technical Department, as well as Production Preparation and OHS services, to develop the widest possible view of energy recovery or loss in the production processes, the level of processing of raw materials, and the assessment of materials based on their cost share. Individual production processes in the total cost pool and the effectiveness of individual production processes were assessed during a **brainstorming session**, trying to determine the possibly wide set of employee burden criteria, especially in terms of occupational health and safety and the ergonomics of workstations. In the next step, the team plans to develop a matrix of connections between individual criteria, creating the largest possible number of connections and direct and indirect impacts with various areas of operation, and then to assign the force and probability with which impacts on employees and the production process can be expected. This set will be the basis for the creation of multi-criteria models in the future. At this stage, the author performed a **SWOT analysis** to determine the strengths and

weaknesses of the analyzed enterprise, as well as opportunities and threats concerning the discussed topic.

Departments and production areas

A number of machining processes were carried out at the MABO I, MABO II, and MABO III, Tooling, Hardening, Plastic Working, Galvanizing, and Painting departments. These processes differed in many aspects, such as energy consumption, automation, ergonomics of the workstation, and inconvenience for the operator. Twelve production processes were selected, which were then grouped according to the most important areas of similarity: automation, ergonomics, and discomfort.

Group I (unergonomic processes)

- Processes of manual grinding after welding and surface treatment;
- Manual welding processes: MIG/MAG, TIG, MMA.

The analysis for group I shows that processes in this group are fairly manual, and the key factor is the low level of ergonomics of the workstation. These processes are the core for most of the products. The ergonomics of grinding and welding depend highly on the characteristics of the product's technical specification and customer requirements. This reason allows for a wide range of production with a very

Table 5. Factors for the SWOT analysis regarding the unergonomic processes (group I) in the analyzed enterprise

Strengths	S	SoI	Weaknesses	S	SoI
Ease of adaptation to the product – since the welding and grinding processes are performed manually by qualified employees, it is easy to perform short-series processes and produce significantly different products.	3	3	Low flexibility of production capacity	4	5
No downtime due to retooling	4	4	Efficiency directly proportional to the level of complexity and manual difficulty of a specific product	5	4
The emission of noise and vapors is directly proportional to the instantaneous production volume	3	3	Difficulty in estimating the amount of work (adequate allocation of human resources) at the stage of production preparation	3	4
Relatively low energy and heat consumption per man-hour of the process	4	4			
Opportunities	S	SoI	Threats	S	SoI
Qualified staff and relatively easy and cheap change of welding and grinding technology (by changing welding or grinding materials) allow for a very wide market share in the prefabrication of structures made of various types of metals.	4	3	High sensitivity to the labor market situation (especially for highly qualified welders)	4	5
The development of large-scale production will bring the potential for the implementation of welding robots, significantly reducing the burden of work for welders in the repetitive welding process	3	4	High saturation of the labor intensity of manual processes (especially grinding) in the situation of growing costs of remuneration of qualified employees creates the risk of an unpredictable increase in the costs of these processes, and thus a reduction in the competitiveness of the conducted production activity.	4	4

S – significance (1 – low, 5 – high); SoI – strength of influence (1 – low, 5 – high).

short time for set up or change-over. On the other hand, the only reasonable improvement would be robotization and automatization of the process, but that would only be possible for high-volume production with very little diversity in the production profile.

Group II (Complex processes)

- Cutting processes on band saws;
- Drilling processes on column drills;
- Cutting processes on CNC machine tools (lathes, milling machines);
- Plastic working processes (presses, benders, guillotines);
- Thermal cutting processes (CO₂ and fiber laser, plasma, gas burner).

In group II the key processes are CNC machining and cutting. All the processes are commenced on specialized machines with adequate safety and ergonomics. Since the company invests in the latest machining technology, energy consumption levels are also optimized. The main field for improvement is loading, including manipulation in loading and unloading, specifically of large and cumbersome pieces.

Group III (arduous processes)

- Airless painting process (wet painting shop);
- Abrasive blasting (sandblasting, shot blasting).

The analysis shows that in group III all the processes in this group are carried out manually in

environments with high levels of discomfort. For the wet painting, harmful fumes are emitted, while high noise and harmful dust emission occur during sand-blasting. Both processes are the key processes for surface treatment for the entire scope of carbon steel manufacturing production, and the key component of the added value of the company's final product. Due to the above reasons, the decision-making field and strategy should be the implementation of new less harmful painting formulations, such as water-based paints, and providing the latest personal protective equipment for operators.

Group IV (High-temperature processes)

These processes are similar due to high electricity and/or heat energy consumption:

- Powder coating process (powder coating shop);
- Hot dip galvanizing process;
- Hardening, tempering, and normalization (quenching) process.

All the processes in group IV are characterized by a high consumption of electrical energy and high emissions of harmful substances, both of which have a very negative impact on sustainability, cost-effectiveness, and the well-being of the operators. On the other hand, all the high-temperature processes are the key in building value for the final product, in many cases having key advantages from the manufacturing perspective. From the decision-making perspective, with the considerations of the cost of electricity, the

Table 6. Factors for the SWOT analysis regarding the complex processes (group II) in the analyzed enterprise

Strengths	S	SoI	Weaknesses	S	SoI
Automation of the loading process and manipulation of the processed detail in the processing field with the use of handling devices, such as overhead cranes, cranes, and gantry as well as forklifts, significantly reduce the discomfort of operators' workstations	3	3	Machining processes carried out on machine tools in an automatic manner and the additional use of manipulators reduce the discomfort of workstations for operators. Unfortunately, the risk of health and safety problems and discomfort increases in direct proportion to the size and weight of the processed products. It is related not so much to the machining process itself, but to close transport and placing the detail in the machining field.	3	4
All machining processes are carried out on machine tools made on the basis of international standards and machine standards, ensuring an adequate level of operator safety, a high level of health and safety, and low operator inconvenience.	4	3			
Opportunities	S	SoI	Threats	SoI	S
All machine tools for complex processes enable the processing of materials with increased anti-corrosion resistance, such as stainless steel or aluminum, which allows the creation of a profile of finished products with the reduction of energy-consuming, high-emission, and burdensome anti-corrosion surface processes, such as galvanizing and/or wet and powder coating.	3	4	Due to the need to have highly qualified operators for conducting production processes on complex process machine tools and due to the shortage of such personnel on the labor market, despite the high productivity of the machines themselves, the production capacity of the machining processes is significantly reduced due to the staff shortages.	3	3

S – significance (1 – low; 5 – high); SoI – strength of influence (1 – low; 5 – high).

Table 7. Factors for the SWOT analysis regarding the arduous processes (group III) in the analyzed enterprise

Strengths	S	SoI	Weaknesses	S	SoI
Wet painting and abrasive blasting processes, since they are performed manually by qualified employees, allow for easy adaptation to the product, production of short-series, and significantly different products.	4	4	The processes of wet painting and abrasive blasting, due to their nature, i.e., high emission of vapors, dust, and noise, are associated with great discomfort, particularly related to health and safety and the need for employees to constantly wear personal protective equipment.	5	4
The versatility of wet painting and abrasive blasting processes allows the downtime resulting from the conversion of stations to be minimized.	4	5	Wet painting and abrasive blasting processes, due to their high consumption of compressed air, which is produced in the enterprise by energy-consuming compressors, cause high energy consumption.	4	4
Opportunities	S	SoI	Threats	S	SoI
Innovations related to personal protective equipment and their implementation at the positions of operators of wet painting and abrasive blasting processes significantly reduce the negative impact of the environment and the discomfort of the work.	3	4	Most of the wet painting and abrasive blasting processes are highly energy-consuming due to the very high consumption of compressed air, which is highly energy-consuming to produce in compressors.	4	5
Innovations in the field of varnish materials and abrasives used in the processes of wet painting and abrasive blasting allow the process time to be shortened or air consumption to be reduced, which significantly reduces energy consumption.	4	3	All wet painting and abrasive blasting processes are associated with the emission of various substances, dust, or noise and are subject to environmental control and integrated emission permits, and the increasing environmental requirements and standards force continuous and high investment expenditures to reduce emissions.	4	3

S – significance (1 – low; 5 – high); SoI – strength of influence (1 – low; 5 – high).

Table 8. Factors for the SWOT analysis regarding the high-temperature processes (group IV) in the analyzed enterprise

Strengths	S	SoI	Weaknesses	S	SoI
Partially automated processes, improving and facilitating the work of operators, significantly reducing the risk related to health and safety and the discomfort of the work.	4	4	All high-temperature processes, due to their nature, i.e., high ambient temperature, emission of vapors, dust, and noise, are associated with great discomfort, particularly related to health and safety and the need for employees to constantly wear personal protective equipment.	4	5
Heat recovery, especially in the area of preliminary heating of the structure before painting and galvanizing, the use of heat to dry the structure in processes, and the accumulation of heat in the oil tanks of the hardening plant, allows for a significant reduction in energy consumption.	4	4	Due to large differences in process and ambient temperatures, high-temperature processes are characterized by large heat losses, which significantly affect the energy consumption of the processes.	4	4
Changing the technology of generating heat from electricity from resistance to induction technology causes a significant reduction in energy consumption	3	4			
Opportunities	S	SoI	Threats	S	SoI
Innovations related to personal protective equipment and their implementation at the positions of operators of high-temperature processes significantly reduce the risk related to occupational health and safety and the discomfort of the work.	3	4	Most high-temperature processes are highly energy-intensive with additionally having a low heat recovery coefficient (the exception is the hardening process and the use of heat to heat the hall in the winter months). The source of energy for these processes is electricity, and its significantly rising price could cause an exponential jump in the costs of these processes.	5	4
Innovations in the field of materials and chemicals used in some high-temperature processes, such as the pickling plant and powder paint shop, enable the speeding up of processes or their implementation at lower temperatures, which significantly reduces energy consumption.	4	3	All high-temperature processes are associated with the emission of various substances, dust, or noise and are subject to environmental control and integrated emission permits, and the increasing environmental requirements and standards force continuous and high investment expenditures to reduce emissions.	4	5

S – significance (1 – low; 5 – high); SoI – strength of influence (1 – low; 5 – high).

key is the scope of the competition: if it is local then it is mitigated by the fact that everyone on the Polish market will face the same circumstances. However foreign competition with lower costs of energy will have an advantage in pricing the product. So, in this case, the market of the end user should be recognized in the decision-making process.

Conclusions

Summarizing the conducted analyses, the author noted many criteria, premises, and conditions by means of which it is possible to evaluate individual production processes in terms of energy consumption or employee burden. For the sake of ordering, the production processes were classified based on common leading conditions referring to the premises of sustainable development. As a result, four groups of processes were created: unergonomic, complex, cumbersome (or arduous), and high temperature. In group I (unergonomic processes), the areas of similarity are automation, ergonomics, and employee discomfort, while the processes are manual grinding (after welding and surface grinding processes) and manual welding (MIG/MAG, TIG, or MMA). In group II (complex processes) the areas of similarity are automation, ergonomics, and arduousness, while the processes are cutting processes on band saws, drilling processes on column drills, cutting processes on CNC machine tools (lathes, milling machines), plastic working processes (presses, benders, and guillotines), thermal cutting processes (CO₂ and fiber lasers, plasma, and gas burner). The next is group III (arduous processes), where the areas of similarity are automation, ergonomics, and discomfort, while the processes are hydrodynamic painting process (wet paint shop) and abrasive blasting (sand-blasting plant, shot blasting plant). The final group is group IV (high-temperature processes), where the areas of similarity are energy consumption (electricity and heat), while the processes are powder coating (powder coating shop), hot-dip galvanizing, and the processes of hardening, tempering, and normalization (quenching).

Each of the analyzed processes is characterized by different energy consumption, employee discomfort, or workplace ergonomics. In terms of decision-making issues, orders are selected for execution from the pool of inquiries flowing to the company, where the order portfolio predetermines the production processes necessary for prefabrication. Understanding the broad impact of various aspects of individual processes on the potential for sustainable development

allows for appropriate planning decisions regarding the building of a portfolio of orders enabling the sustainable development of the company.

To sum up, the current situation of the company, considering the immediate and future environment, as well as the organization itself, its business model, and internal resources, does not allow for significant and drastic changes in the basic technological processes. Investment tasks, along with research and development activities, are carried out on an ongoing basis, and innovative potential is built in through subsequent implementation projects. Moreover, only a part of the company's production potential is used to produce its own products, and the remaining part of its potential is used for external orders based on the documentation and requirements of the client. Due to the above, only cumulative activities consisting in the continuous optimization of processes combined with modeling the portfolio of orders passing through the production space allow for synergy and the sustainable development of the company.

In the context of future research directions, the next research task in this area will be modeling with the use of multi-criteria decision support models aimed at supporting operational activities and decision-making processes for creating an investment policy, building a portfolio of orders, or creating further products.

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52. Dr hab. inż. Przemysław Skotniczny, prof. IMG PAN, Instytut Mechaniki Górotworu Polskiej Akademii Nauk, Kraków, Poland
53. Assoc. Prof. Ing. Lydia Sobatowa, PhD, Technical University of Košice, Košice, Slovakia
54. Dr hab. inż. Jacek Selejdak, prof. Czestochowa University of Technology, Częstochowa, Poland
55. Dr inż. Wojciech Tuchowski, West Pomeranian University of Technology in Szczecin, Szczecin, Poland
56. Dr inż. Mirosław Wielgosz, Maritime University of Szczecin, Szczecin, Poland
57. Dr inż. Bogusz Wiśnicki, Maritime University of Szczecin, Szczecin, Poland
58. Ing. Alan Vasko, Ph.D., University of Žilina, Žilina, Slovakia
59. Srđan Vukša, Faculty of Maritime Studies University of Split, Split, Croatia



Maritime University of Szczecin

The Maritime University of Szczecin (MUS) continues the tradition of marine-related education at Szczecin's maritime schools that was established in 1947. Since then, it has developed dynamically and maintained the highest standards in all areas of research and education.

MUS is recognized by the maritime industry as an important research centre developing marine engineering, navigation, transportation engineering and many other fields. MUS provide research services by **Green Energy – laboratory of wind power plants**, **Marine Fuel and Lubricating Oils Laboratory**, **Maritime Risk Analysis Center** and **Marine Power Plants Laboratory**.

Experts at the University develop innovative concepts like the LNG terminal in Świnoujście. The **European LNG Training Centre** (at MUS) provides the necessary training and awards the required qualifications for operating the terminal LNG equipment and LNG tankers.

The **Baltic Fishing Training Centre in Kołobrzeg** is a new MUS unit, established in June 2013. There are plans to set up a European Maritime Education Centre in co-operation with other universities of the Baltic states. This project involves two MUS training units, the Marine Traffic Engineering Centre and the Marine Rescue Centre. These units, equipped with several state-of-the-art simulators, will be run a broad training courses for Polish and foreign seafarers of all ranks.

The **Marine Rescue Training Centre**, one of the largest and best equipped centers of its type in Poland, offers training courses covering areas such as safety, life rescue, health security and environment protection. Participants are trained to respond in extreme emergency situations.

The **Training Centre for Marine Officers** runs training qualifications and specialized courses for merchant and fishing fleets officers.

The education of mariners calls for thorough onboard seamanship training. Part of this training takes place aboard the modern research-training vessel **Navigator XXI**.

MUS graduates, with an excellent academic background of theoretical knowledge and practical skills, become specialists recognized in Europe and internationally. At present, students can choose a program at one of our five faculties, all conferring bachelor, master in Polish, or in English (selected programs). Doctoral studies are possible at two faculties: Faculty of Marine Engineering and Faculty of Navigation.

There are five faculties at the Maritime University of Szczecin:

1. Faculty of Computer Science and Telecommunication

The following field of study is available:

- Computer Science

2. Faculty of Engineering and Economics of Transport Engineering

The Faculty of Engineering and Economics of Transport Engineering offers courses in four major fields:

- Management and Production Engineering
- Transport
- Logistics
- Management

3. Faculty of Marine Engineering

The following field of study is available:

- Mechanical Engineering

4. Faculty of Mechatronics and Electrical Engineering

The following field of study is available:

- Mechatronics

5. Faculty of Navigation

The Faculty of Navigation offers courses in four major fields:

- Navigation
- Transport
- Geodesy and Cartography
- Naval Architecture

Maritime University of Szczecin provides education to professionals who succeed in finding jobs on the sea and in land. Our graduates are well prepared to meet the requirements of the employment market – English-speaking and equipped with modern knowledge.

Our education programmes comply with requirements of STCW Convention. Our training centres provide continuing education on safety and professional development.



Maritime University of Szczecin

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The MUS Innovation Centre is a company established by the Maritime University of Szczecin and it was founded in August 2013. We were established in response to growing interest in solutions that arise at the Maritime University of Szczecin – one of leading maritime universities in the world.

Our main goal is to provide these solutions to the market. As an independent company, but working closely with the University, we are your first and last stop on the way to use the knowledge and skills of the university faculty.

Our main task is to commercialize the **results of scientific research and inventions**. We also offer the opportunity to benefit from our **modern laboratories, research facilities and highly qualified staff (R&D)**.

We are especially interested in collaborations in the following areas:

- **Research, expertise, analysis, opinions, training**
- **Sale of licenses (exclusive and non-exclusive)**
- **Establishing a new company with or without VC/seed involved (spin off, spin out)**
- **Other kinds of IPR sale**
- **Joining consortia with other public and private bodies**
- **Project implementation**

If you have any questions please do not hesitate to contact us. More information about our services can be found on www.innoam.pl.

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