Journal of TransLogistics

Volume 9(19), number 1, 2023

LOGISTICS SCIENCE CLUB

Wrocław University of Science and Technology

BazTech

Faculty of Mechanical Engineering

Journal of TransLogistics

Volume 9(19), number 1, 2023

Wroclaw University of Science and Technology Publishing House
Wrocław 2023

Pawel Zajac (Editor-in-Chief, Secretary of the Editorial Board)

Editorial Staff: Antoni Witczak (Cover design)

English proofreading: Biuro Tłumaczeń Alingua Sp. z o. o.
10/5 Szlak st. 3, 1161 Kraków

Publisher: Wroclaw University of Science
and Technology Publishing House
(WUST Publishing House)
27 Wybrzeże Stanisława Wyspiańskiego st.,
50370 Wrocław, Poland
https://www.oficyna.pwr.edu.pl/

Address for correspondence: Journal of TransLogistics
48 Smoluchowskiego st., room 12, building "B-8",
50371 Wroclaw, Poland
mail: jtl@pwr.edu.pl

Free access: https://www.dbc.wroc.pl/dlibra/?language=en
https://journaloftranslogistics.pwr.edu.pl/

ISSN 2450-5870
ISSN 2956-5375, Online

DOI: https://doi.org/10.37190/JoT2023

The Journal of TransLogistics (ISSN 2450-5870) is indexed
in the Polish Technical Journal Contents database – BAZTECH
and the database of the Digital Scientific and Professional
Polish Electronic Journals (ARIANTA).

All the scientific articles have received two positive reviews from independent reviewers.

Our impact factor is not yet registered

REVIEWERS (2023)

Anna Brdulak (PL)
Egidijus Dragašius (LT)
Leszek Gardyński (PL)
Justyna Grześ-Bukłaho (PL)
Jarosław Jajczyk (PL)
Krzysztof Junik (PL)
Krzysztof Lewandowski (PL)
Mohammad Al Khazali (CZ)
Barsan Narcis (RO)
Tomasz Nowakowski (PL)
Tomislav Rozic (HR)
Emilia Skupień (PL)
Mateusz Zając (PL)
Maciej Zawiślak (PL)

INFORMATION FOR AUTHORS

Journal of TransLogistics (ISSN 2450-5870) is published by the students of LOGISTICS Research Group, which has been active at Wroclaw University of Technology, Faculty of Mechanical Engineering (since 2004). The invitation to publish a scientific article is addressed especially to those who are at the beginning of their scientific career: they have already written their engineering or master thesis, perhaps they are working on their doctorate, on their invention. The editorial staff, made up of young people, will guess your fears before writing your first article and do their best to make the submission process go smoothly.

The annual scope

- Works of Student Research Groups that are summaries of stages or entire research projects,
- Trends and determinants of development in transport logistics,
- Strategy analysis and formulation in transport logistics,
- Logistics centers for intermodal transport of integrated cargo units – aspects of organization, operational technology and applied technology,
- Automatic identification of vehicles/cargoes/persons in logistics and transportation systems,
- Electronic documents in transport and logistics – EDI (electronic document interchange), e-signature,
- Packaging and storage technologies in logistic transport chains (cold supply chains),
- Logistic issues in water transport (inland and maritime),
- Logistic issues in air transport,
- Logistic issues of pipeline transport,
- Logistically integrated vehicle recycling system,
- Logistic issues in transportation systems that operate autonomous vehicles and robots,
- Vehicle (including electric) traffic engineering and theory,
- The Journal is not closed to publications from across the field of mechanical engineering.

Terms and conditions of publication

The annual Journal of TransLogistics (ISSN 2450-5870) publishes only original papers written in English or in Polish. English translations of the title, summary and key words are done by the Author after being notified by the Editorial Office on the outcome of the review process and after making the necessary adjustments in accordance with the suggestions of the referees. Acceptance of papers for publication is based on two independent reviews commissioned by the Editor. Publication fee: free of charge.

Word (docx) file containing the content of the article should be sent to the edytorial system: https://www.editorialsystem.com/editor/tlog/

Technical requirements

The manuscript should include: name of authors, title, abstract and keywords that should complement the title and abstract (in Polish and in English), the text in Polish and English with a clear division into sections).
The Editor reserves the right to abridge and adjust the manuscript. All submissions should be accompanied by a submission form.
Detailed guidelines for Authors, including evaluation criteria, can be found on the journal's website https://journaloftranslogistics.pwr.edu.pl/

Editor contact info

Editorial Office of "Journal of TransLogistics", 48 Smoluchowskiego st., 50371 Wroclaw, Poland.

DOI: 10.37190/JoT2023_01

Anna SMOK*

THE IMPACT OF THE PANDEMIC ON THE DEVELOPMENT OF PACKAGING VENDING MACHINES IN POLAND

Keywords: *parcel machines, courier deliveries, last mile, COVID-19 pandemic*

The COVID-19 pandemic has affected many aspects of human life. In the described case, the impact of the pandemic on the last mile will be discussed in more detail. At the very beginning, the topic of the last mile was introduced, as well as how it relates to parcel machines. Then, in the second point, the changes that took place during the pandemic in the online shopping market were presented. In the third point, the issue of parcel machines was raised, where the demand for courier services in Poland was described based on the UKE report and the demand for parcel machines was discussed. The fourth point presents the detected problems related to the emerging parcel lockers as well as ways to solve them and measures for the machines to stay on the market. The aim of the article is to present the impact of the pandemic on the development of the parcel machine service in Poland and to present the proposed directions for further development.

1. INTRODUCTION

Nowadays, we live in a dynamically changing world. People's expectations of courier shipments are getting higher and higher. It is no longer enough to deliver the package intact. Today everyone has different needs: for some, the price will be necessary; for others, the speed of delivery will be crucial; and for others, the method of delivery and flexibility of collection are essential apart from the price, time, and security factors. Therefore, parcel machines, commonly known as parcel lockers, were created to facilitate parcel collection for the customer at the right moment. Over the last two years, the demand for courier services has increased, which is related to the outbreak of the COVID-19 pandemic. Due to the easy transmission of the virus by droplets, the consumers were forced to limit contacts to a minimum. This was related to the established legal provisions, including further restrictions on the number of people in stores and people's internal fears. Most of society was concerned about their health, which resulted in partial changes in consumers' shopping habits. That, in turn, affected all branches, but logistics faced the biggest challenge. Broken

* Wroclaw University of Science and Technology, Faculty of Mechanical Engineering, Poland.

logistic chains and the increase in demand for last-mile services have forced many changes, including increased flexibility throughout entire supply chains.

The article aims to present the impact of the COVID-19 pandemic on the last mile service, using parcel machines as an example, and to propose future solutions that combine the functionality of parcel machines with their aesthetics.

The second point will discuss the topic of last-mile service. What it is, its concerns, and how the pandemic affected its development.

The third point describes courier services and the service of parcel lockers as well as the change in the market related to the demand for parcel machines during the pandemic.

The fourth point presents the problems related to the increasing number of parcel lockers on the market and ways to meet the requirements of the environment.

The fifth section summarizes the topic.

2. LAST MILE SERVICE

The concept of the last mile can be described as "a set of related organizational activities in the spheres of transport and logistics, concerning the implementation of deliveries on the very last stretch of the road and, more precisely, the delivery of shipments to end customers" [1]. It focuses on the last stage of delivery, which is the most expensive and problematic area in the entire supply chain. This process has many problems, such as home delivery or DTD (door-to-door) delivery, because they involve additional costs or pollution.[2]

Last mile service includes not only a courier, parcel, and customer but also facilities enabling direct collection or sending of the shipment [3,4]. This can be done via parcel machines, stationary post offices, and authorized facilities.

The concept of a parcel machine is understood as a device resembling a rack with shelves on which parcels can be collected or sent. In Poland, the leader among parcel machines is InPost, with its network of parcel machines. For this reason, the term parcel machine is often used interchangeably with the term parcel locker, a trademark of InPost. The reason for this can be found in the fact that this brand pioneered parcel machines on the Polish market. In addition to the possibility of collecting parcels from InPost parcel machines, they can also be sent or redirected to stores cooperating with the company as well as to parcel machines belonging to other companies, such as DHL or Poczta Polska. Parcel machines can be found in Biedronka and Carrefour outlets and supermarkets, in Żabka stores, ORLEN gas stations, and RUCH kiosks. [4]

Recently, customers have been more willing to choose courier services, pick up/drop off at points, or parcel lockers, which is closely related to the increasing number of Internet users who are more and more willing to make purchases in a virtual environment. In 2020, over 60% of online shoppers chose delivery to parcel machines [4]; therefore, it can be concluded that the pandemic contributed to an

increase in the demand for courier services and the number of parcel pick-up/drop-off points.

The analysis of E-commerce reports in Poland from 2019-2022 made in cooperation with Gemius and the Chamber of Electronic Commerce, allowed us to conclude that during the COVID-19 pandemic, online customers' behavior changed. When we compare the number of Internet customers in relation to the number of people using the Internet, we can see a significant increase in the number of people making online purchases (Figure 1). The method of collecting the parcel has also changed. Before 2020, home delivery by courier was the most popular choice, while after 2020, collection at a parcel machine became the most popular form (Figure 1).[5]

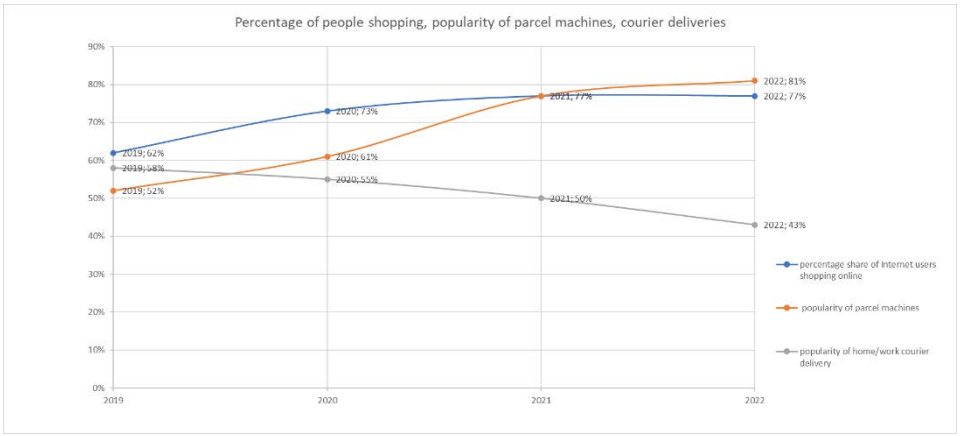


Figure 1. Number of online shoppers, popularity of vending machines parcels, deliveries [5]

In response to the question about what motivates them to shop online, Internet customers most frequently mentioned 24/7 availability, the lack of need to travel directly to the store, and unlimited selection time. As can be seen in the radar chart below (Figure 2), customers shopping online indicated these factors more often as necessary in 2020 than in other years. Knowing the circumstances related to the pandemic, the difficulties in doing stationery shopping, and concerns about contacts with other people, it can be concluded that there is a link between the motivators for online shopping and the pandemic.

Analyzing the number of Internet users, one can notice a systematic increase in the number of people using it, and currently, in 2022, there will be about 30 million users. Compared with the number of people using the online environment to shop, one can see uneven changes. In 2020, the number of customers increased by about 10% compared to 2019, while in 2022, their percentage share did not change and the market was saturated. One can see similarities by analyzing these differences and considering the context of the pandemic. The graph shows a significant increase in the percentage of online shoppers in 2020 compared to the previous year. In 2021,

people got used to the prevailing situation, and therefore there was only a slight increase in the percentage. In 2022, all restrictions on in-store shopping were lifted, and the number of online customers remained constant.

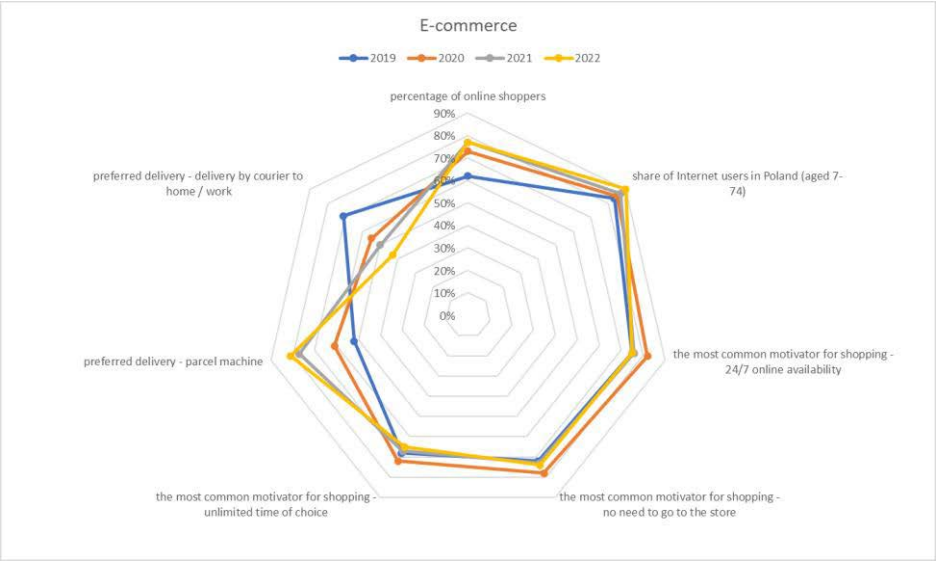


Figure 2. Behaviors in the e-commerce market [5]

Another dependence that can be seen is the increase in interest in delivery to a parcel locker instead of direct delivery to home or work by a courier. As seen in the chart (Figure 2), in 2020, the interest in courier services decreased compared to the previous year in favor of parcel machines. In the following years, the popularity of parcel machines maintained an upward trend.

Thus, analyzing the presented chart in the context of the COVID-19 pandemic, it can be seen that 2020 was a year different from the others. In almost all of the analyzed criteria, 2020 differed from the forecasts that assumed maintaining the level from previous years or stable growth. For the most common motivator for shopping, it can be noticed that the results obtained this year were different from the other analyzed years. The increase can also be seen in the percentage of online shoppers.

The COVID-19 pandemic caused the need to introduce various types of innovations in the field of logistics services, in particular for individual consumers. These innovations concerned not only the means of last-mile delivery but also the product packaging system and return processes. These innovations resulted from the development work of producers and logistics operators and were intended to improve the quality of consumer service. These solutions would probably appear in the coming years regardless of the pandemic situation in the world, but the COVID-19 pandemic has undoubtedly accelerated these processes.

When analyzing the research conducted for Publicis Groupe by Starcom and presented in the article "Covid skills" - what we have learned and what will stay with us for longer - the results of the HX Stud [6], one can refer to the chart showing "Online grocery shopping, food delivery, shopping". This chart compares three periods (the pandemic's beginning, the present, and the future) by online shopping demand (groceries, food delivery, and stockpiling). Respondents answered questions about the extent to which they made online purchases in each period. According to the graph "Online grocery shopping, food delivery, shopping", there is an increase in demand for services related to delivering various goods to individual customers. It can also be seen that almost 20% of respondents order food with home delivery, and less than 10% still intend to shop for groceries online.[6]

The second graph, "Non-food purchases, medicines, and supplements online", was divided into three periods; in this case, two shopping products were distinguished (non-food and medicines, supplements). The analysis of the charts shows that about 40% of people continue to make non-grocery purchases, and about 5% made this type of purchase more often at the beginning of the pandemic than now. [6]

As it turns out, the customer must choose the place and time of delivery or collection. The advantage of parcel lockers is the ability to pick up a parcel at any time, which is more difficult in the case of courier deliveries because of the necessity to make an appointment in advance or wait for the delivery within a predetermined hourly interval. However, this is only sometimes successful; in such cases, it ends with leaving notice and having to collect the parcel in person. Another advantage of ordering parcels through parcel machines is how you can pick up a previously placed parcel. It is not complicated; one only needs to enter an individual code generated only for this specific shipment and then take it out of the parcel machine slot and close it. The machine automatically opens the box after reading the code to facilitate the search for the parcel's location.

3. COURIER SERVICES AND PARCEL LOCKER SERVICE

3.1. THE DEMAND FOR COURIER SHIPMENTS IN THE ERA OF THE COVID-19 PANDEMIC

During the COVID-19 pandemic, the demand for courier services increased, in part because of the e-commerce market. UKE (Office of Electronic Communications) presented trends of change in *the Report on the state of the postal market in 2020.* In contrast, a sharp increase was recorded in 2020. This was mainly due to the virus's global spread, which caused the declaration of a pandemic, as well as a number of restrictions and limitations on consumer movement. Comparing the trend line of courier shipments to letter mail shows that the latter has a declining market share. [7]

This is related to the convenience and ease of posting and delivery and the ability to track the package using a website where the package status and expected delivery

date can be checked. These types of parcels are usually delivered in a shorter time compared to traditional postal services [4].

3.2. THE DEMAND FOR PARCEL MACHINES IN THE ERA OF THE COVID-19 PANDEMIC

Based on the report "Rudolf can't handle it alone - the market of parcel machines in Poland" [8], created by Colliers, it can be found that as many as 85% of respondents, having the choice of the type of delivery, regularly choose the option of delivering the parcel to the parcel machine. More than a third (32%) were in favor of choosing this method whenever possible. As a result, almost 40% of all delivered parcels are delivered to the parcel lockers, and 50% are delivered directly to the customer's place of residence [8]. As it turns out, almost 70% of people use the Internet to shop and, upon seeing the possibility of choosing a parcel machine as a delivery form, make a purchase decision. Thus, it can be concluded that they constitute a motivating element [4].

The period of the pandemic has contributed to an increase in the demand for courier deliveries and an increase in the number of parcel machines. By analyzing *Out-of- home* reports *delivery in Europe 2021 report* and *Out-of- home delivery in Europe 2022 report*, an increase in the number of parcel machines installed and used can be noticed. For 2020, compared to 2019, it was an increase of over 75%. However, in 2021, compared to 2020, by more than 80%, respectively. This marks a spectacular increase in the number of parcel machines in just 2 years. [9,10]

4. PARCEL LOCKERS

4.1. PROBLEMS

Before the pandemic, the entire distribution network to the end customer was gradually developing. When some stores were announced to be closed, restrictions on the number of people staying in them and restrictions on movement were introduced, and the current concerns about people's health began to gain strength. As a result, people have attempted to avoid contact with other people to reduce the risk of contracting the virus, contributing to increasing demand for last-mile services. In order to meet the requirements, many companies have come up with various initiatives to gain or retain customers. Understanding the market demand, InPost increased the number of its parcel lockers, e.g., by placing vending machines in villages. However, the insatiability of the market caused other entrepreneurs to take advantage of this opportunity. As was previously described in more detail, many entrepreneurs have already been providing or are planning to start providing services on the Polish market, not the same as but similar to the operation of InPost parcel machines. This, however, causes increasing concern among the public. The mere possibility of collecting a parcel from a parcel machine located in the vicinity (up to 10 minutes' walk) from the place of residence is acceptable. Difficulties resulting

from the location and the number of parcels delivered are becoming a growing problem. Residents adjacent to parcel lockers are increasingly dissatisfied because frequent deliveries and pick-ups of parcels by cars and customers cause an increase in noise and traffic in the area.

Another area for improvement is the method of collecting parcels. Customers frequently come by car and park not only in the designated places but also in the forbidden ones, which later translates into difficulties in the movement of residents of the area (e.g., parking on the pavement, parking the car partly on the roadside, partly on the road). However, a bigger problem is the occupancy of parking spaces belonging to residents by those collecting parcels, which causes parking difficulties. On the other hand, parking cars on green belts causes their destruction, which translates into the place's aesthetics. This means that a specific group of residents may not agree to the placement of new parcel lockers in their area, and even as it happened in one of Warsaw's districts, Ochota, residents objected to the already existing parcel locker, citing the issues mentioned above as a reason [11].

Kuba Czajkowski from Miasto Jest Nasze mentions another problem in his publication: the appearance of parcel machines. According to the author, the design should be uniform and constitute an element of infrastructure, such as bus stops [11], which have a unified form, are easily recognizable and at the same time fit into the urban infrastructure. Initially, there were few parcel lockers, and almost all belonged to one owner; therefore, they appeared uniform everywhere. Now an increasing number of competing companies are entering the market. The lack of standardized standards for parcel machines' performance, size, and aesthetics will result in the newly created parcel machines in different colors and sizes.

4.2. SOLUTIONS

All aspects must be considered to improve the aesthetics of the places of the current or future deployment of parcel machines.

The first of these may be the choice of place. It should consider the opinions of customers and local residents as well as technical matters, and more specifically, depend on access to power, the possibility of being reached by a courier’s delivery car, or the ease of finding the parcel locker.

The second aspect may be the very appearance of the parcel locker. The best solution, in this case, would be to create a legal provision that would regulate the size, color, and location of the parcel machine. Such facilities should also not be close to public institutions, such as churches, museums, historic tenement houses, or the main square. This is because such placement can negatively affect the surrounding landscape. The colors should also be standardized. An example may be the approach of Żabka stores, which, while placing their parcel lockers, try not to spoil the image of the area.

The third aspect may be adding the possibility of using a parcel machine to store previously ordered groceries in, for example, grocery stores like Biedronka. This would require a refrigeration unit to be built into part of the parcel locker, and it

would also require consideration of the problem with frozen products. Limiting the order function only to products that do not require freezing would save space for cold storage or for ordinary parcels. However, this would limit the shopping possibilities or the number of people using this type of service. However, adding the possibility of storing frozen food requires more advanced preparation of the machines. However, in order to make such a decision, it would be wise to do a market analysis at the very beginning and find out what percentage of people ordering groceries would like such a solution.

5. SUMMARY

The parcel machine market has existed in Poland since 2009 and has expanded to foreign markets. The leading representative, currently holding almost 90% of shares in the Polish market, is InPost [8]. As can be seen, the market is not saturated yet because there are plans to build many more contactless parcel collection points, not only by the leader but also by the competition, which is still growing. The COVID-19 pandemic has significantly contributed to the increase in consumers' interest in online shopping and contactless deliveries. This increased the demand for both courier services and the number of parcel lockers. This allows the competition to launch their vending machines, especially since a further increase in demand for parcel lockers is forecasted. In order to remain the market leader, InPost introduced shipments delivered on the same day as they were sent without charging additional fees. This allows them to stand out from the competition. However, to survive in the long term in this increasingly demanding market, it is necessary to take care not only of the aspects related to delivery time but also the aesthetic aspects. Fundamental here is the estrangement of parcel machines' appearance and the correct location choice (introducing parcel machine-free zones, such as next to a historic building). It is also important to ensure that the location of the parcel locker allows for free parking next to it, and that the collection of the parcel does not damage the surroundings or threaten other road users. Conducting a prior environmental survey and determining whether the parcel locker is located at an appropriate distance from the places of residence to minimize the impact of noise from unloading and collecting parcels should reduce the likelihood of removing the machine in the future (as it happened in Warsaw in the Ochota district).

LITERATURE

[1] BRACH J., *Obecne zmiany na europejskim rynku pojazdów samochodowych do przewozu ładunków- analiza z perspektywy strony podażowej*, Wydawnictwo Uniwersytetu Ekonomicznego we Wrocławiu, 2019r, s.92

[2] JUHÁSZ J., BÁNYAI T., *Last mile logistics: an integrated view*, IOP Conference Series: Materials Science and Engineering, Volume 448, XXIII International Conference on Manufacturing (Manufacturing 2018)7–8 June 2018

[3] KOWALSKI A, ŻAK J., *Wybrane aspekty wyboru lokalizacji „punktów ostatniej mili" w łańcuchu dostaw,* Prace Naukowe Politechniki Warszawskiej, 2018r, s.63-72
[4] KOŁATA D., *Ostatnią milą do automatu paczkowego,* Logistyka, nr 5/ 2020, s.13-17,
[5] E-commerce w Polsce *2019-2022*, Gemius dla e-commerce Polska, https://www.gemius.pl/wszystkie-artykuly-aktualnosci/e-commerce-w-polsce-2020.html (data dostępu 18.11.2022r.)
[6] Publicis Groupe, *Starcom: „Covidowe umiejętności" – czego się nauczyliśmy i co z nami zostanie na dłużej – wyniki badania HX Study*, https://infowire.pl/generic/release/574988/starcom-covidowe-umiejetnosci-czego-sie-nauczylismy-i-co-z-nami-zostanie-na-dluzej-wyniki-badania-hx-study (data dostępu 25.03.2022)
[7] UKE, *Raport o stanie rynku pocztowego w 2020 roku* (data dostępu: 31.05.2021 r.)
[8] CHMIELEWSKI M., *Rynek automatów paczkowych w Polsce | Rudolf sam sobie nie poradzi* 20.12.2021rok,
[9] Last mile Experts, *Out-of-home delivery in Europe 2021 report,* kwiecień 2021r.
[10] Last mile Experts, *Out-of-home delivery in Europe 2022 report,* wrzesień 2022r.
[11] Ilona Mrozowska, *InPost, SwipBox, Allegro, Poczta i inni: rośnie biznes w automacie 17*.05.2021rok, https://handelextra.pl/artykuly/249367,inpost-swipbox-allegro-poczta-i-inni-rosnie-biznes-w-automacie (data dostępu: 08.04.2022)

Corresponding author:
Anna Smok, smoktyfel@gmail.com

DOI: 10.37190/JoT2023_02

Rafał BERNAT, Bartłomiej LOREK[1], Mariusz KOSOBUDZKI

ANALYSIS OF THE EFFECTIVENESS OF CHANGES INTRODUCED TO THE SUSPENSION SYSTEM OF THE SCORPIO 7 MARTIAN ROVER

Key words: *Martian rover, off-road vehicle, suspension, Scorpio, University Rover Challenge*

The paper describes an innovative solution for the suspension system of the Scorpio 7 Martian rover, developed based on the previous generation of the vehicle – Scorpio X. The machine was intended to participate in Martian rover competitions from the Rover Challenge series. The document presents an analysis of the parameters characterising the discussed suspension system, with heavy emphasis on the mass of the platform, deflection under working conditions, amount of space required and angular positions of paramount components. Those characteristics are compared to values describing the systems of Scorpio X.

1. INTRODUCTION

In recent years interest in space exploration has been very high. The largest space agency, NASA, has presented its plans to prepare for the Artemis program, a manned mission to the Moon in 2024, and to send another unmanned mission to Mars. Currently, Mars is being studied by 8 separate scientific missions from all over the world. However, technologies sent to distant planets are first developed and tested on Earth. Inspiration for these technologies is sought by organising competitions such as the Rover Challenge series. [1] These competitions are formalised, meaning they are conducted according to established rules and regulations, and the selection of teams for the competitions is preceded by a preliminary stage. Student-built Mars rovers taking part in the competition are an important source of ideas for all space agencies, including NASA. For students, they present opportunities to compete with teams from all over the world, improve their cognitive and technological knowledge, and develop their own ideas and technologies [2]. An example of a Mars rover developed by students from Monash University in Melbourne is shown in Figure 1.

[1] Wroclaw University of Science and Technology, Faculty of Mechanical Engineering, Department of Fundamentals of Machine Design and Mechatronic Systems, Poland

Fig. 1. Rover built by students from Monash University in Australia, presented at the University Rover Challenge 2019

Scorpio 7, a rover designed by students affiliated with the Student Scientific Association OFF-ROAD and operating at the Department of Off-Road Vehicle Engineering of the Faculty of Mechanical Engineering of the Wrocław University of Science and Technologies, meets the requirements set in the regulations of the Rover Challenge competitions. Due to the simulated Martian or lunar conditions during the competitions, all vehicles must be of the off-road class. The basic regulatory requirements for rovers relate to their dimensions: the vehicle must fit in a cube with an edge of 1200 mm and weigh no more than 50 kg [3]. In addition, vehicles are required to have the ability to drive autonomously. [4]. A photo of the Scorpio 7 rover, participating in the competition, and its model, made in the SolidWorks environment, are presented in Figure 2.

Fig. 2. The Scorpio 7 rover at the URC 2022 competition (left) and its 3D model (right)

Participation in the competitions, analysis of the achieved results and rivalry with other teams are the most important sources of data that allow for the continuous development of owned technologies.

2. CONSTRUCTION OF THE SCORPIO X SUSPENSION SYSTEM

The suspension of the Martian rover Scorpio X was constructed based on the rocker-boogie suspension concept, which is used by NASA in the construction of such rovers as Curiosity and Perseverance [5]. A conceptual diagram of this type of suspension is visible in Figure 3. In order to reduce weight and simplify the design, the number of wheels used in the bogie, typically four, was reduced to just two.

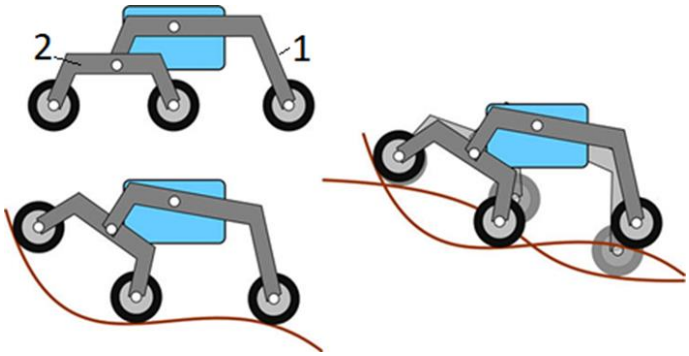


Fig. 3. Diagram of the rocker - boogie suspension system; 1 - rocker, 2 – boogie

The rockers on both sides of the Scorpio X rover were connected through a differential mechanism. The mechanism consisted of a single aluminium beam, supported by bearings in the middle of its length. It was connected to the rockers through a system of pushrods and levers. This solution performed well in fulfilling its tasks but was heavy and required placement in a specially designed cage, taking up a significant amount of valuable space. Additionally, the beam moved in a horizontal plane, which was not favourable due to possible collisions with the vehicle frame and allowed for increased rocker movement. In order to eliminate these drawbacks, it was decided to improve the suspension system parameters in the new generation of the rover, particularly to reduce the total weight and the amount of space occupied by the system during full range of motion. During the design phase, limitations resulting from manufacturing and assembly had to be taken into consideration. Loads acting on individual elements of the new suspension system should not cause plastic deformation, and the entire system should be optimised in terms of mass, volume, and placement. [6]

3.CHANGES INTRODUCED TO THE SCORPIO 7 SUSPENSION SYSTEM

In the Scorpio 7 rover, similarly to Scorpio X, the differential mechanism is attached to the rockers through a pushrod supported by ball joints. The mechanism is mounted on the rear wall of the vehicle's body, and its movement takes place in a plane perpendicular to the floor. The construction of the new system is presented in Figure 4. Intermediary elements, such as sway bars or additional levers are not necessary in the Scorpio 7 suspension [7].

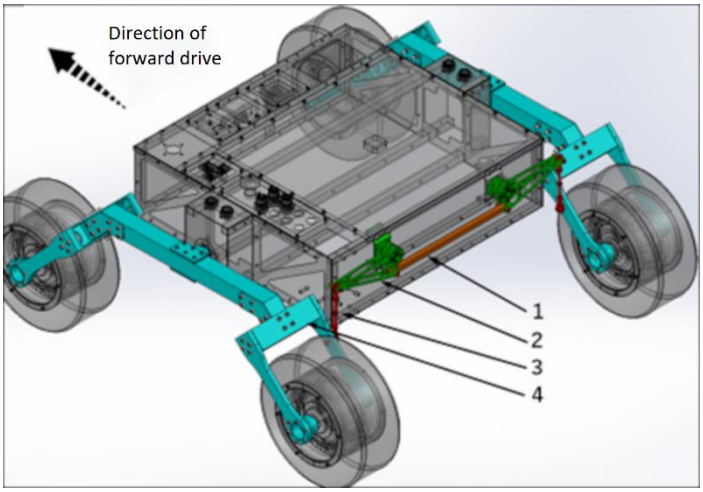


Fig. 4. Scorpio 7 suspension system diagram; 1 (orange) - beam, 2 (green) - triangular beams, 3 (red) – pushrod, 4 (blue) – rocker. The arrow shows the direction of forward drive.

Due to the vertical orientation of the mechanism, great freedom in shaping particular dimensions and individual suspension parts was achieved, which allowed for design so as to minimise forces transmitted from the suspension. The new mounting method induced a change in the pushrod mounting location in relation to the rocker. In Scorpio X, this element was mounted closely to the rocker's axis of rotation. Since pushrod is responsible for transmitting rotational moments from the rocker to the differential beam, its minute distance from the axis of rotation resulted in large forces transmitted by this element. In Scorpio 7, due to the placement of the differential beam on the rear of the vehicle, it was necessary to move the pushrod back, up to the rocker's end. This significantly increased the lever arm and reduced the forces acting on the pushrod.

In order to more evenly distribute forces acting on the frame at the mounting location, it was decided to divide the differential beam, which was a single element

in Scorpio X, into a mechanism consisting of five separate beams. Four beams with a shape derived from a triangle (further referred to as "triangular beams") - two on each side of the vehicle - as well as a square cross-section beam were used. Schematic showing the construction of the mechanism can be seen in Figure 5.

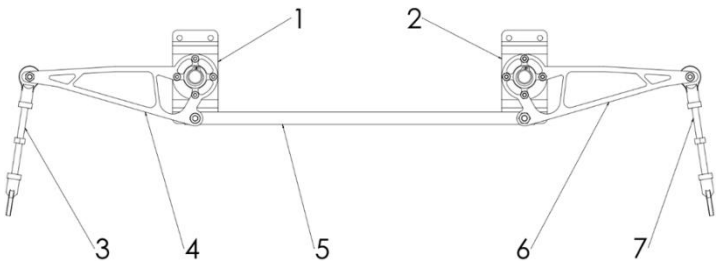


Fig. 5. Diagram showing differential beam mechanism with pushrods; 1 - left mechanism mount, 2 - right mechanism mount, 3 - left pushrod, 4 - left triangular beams, 5 - beam, 6 - right triangular beams, 7 - right pushrod

The triangular beam, shown in Figure 6, was made by laser cutting from 6060 aluminium sheet with a thickness of 4 mm. Dimensions significant for the kinematics of the suspension are arm lengths of 160 mm and 40 mm, located at the vertices of the right triangle, which is shown in Figure 6. The beam connecting the left and right sides of the mechanism is made from the same material as the triangular beams. It is a rectangular pipe with dimensions of 12x12x1 mm and a length of 340 mm.

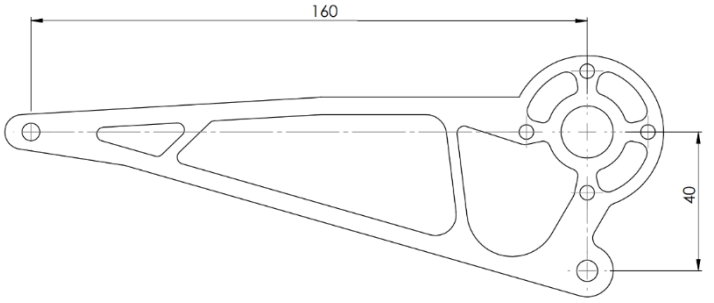


Fig. 6. Drawing showing triangular beam's relevant dimensions

The use of two triangular beams on each side of the mechanism (Fig. 4) is redundant in terms of kinematics but brings benefits related to the assembly of pushrods.

4. ANALYSIS OF LOADS IN THE SUSPENSION SYSTEM

Similarly to its predecessor, the differential mechanism in Scorpio 7 is subjected to deformations due to the forces generated by crossing uneven terrain. The triangular beam shape was designed to have the lowest possible mass while maintaining high bending rigidity. Optimisation of the shape was carried out using results from the FEM analysis [8] performed in SolidWorks. The simulation was intended to show the magnitude of deformations occurring during loading. The mesh was built using the TETRA 10 finite element and a maximum edge length of 1 mm. Loads were assigned based on the results from the multibody dynamics simulation (MDS) [9] performed in MSC Adams [10] for the full range of suspension motion. The maximum element stress results were used to calculate the deformations. Additionally, the following boundary conditions were applied:

- Fixed displacement at the pivot (bearing) location
- Force, with a magnitude of 6 N along the X axis, 23,5 N along the Y axis and -1,5 N along the Z axis, was applied to the pushrod mounting location
- Force, with a magnitude of 78,5 N along the X axis, -26,5 N along the Y axis and -1 N along the Z axis, was applied to the differential beam mounting location

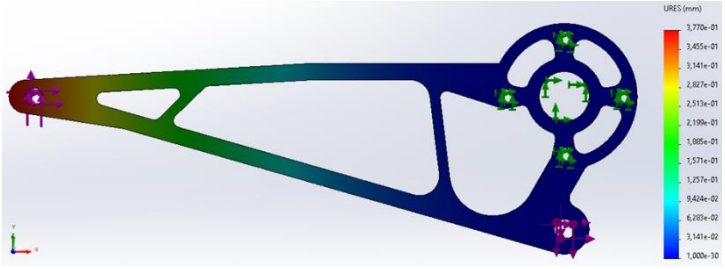


Fig. 7. Displacement map of the loaded triangular beam

The results of the calculations are shown in Figure 7. The largest deformation of the beam (as a result of bending) occurs near the point of attachment to the pushrod and equals about 0.37 mm. This value does not depend on differential system movement. Elasticity of this element allows for the pushrod's movement despite the constant angular position of the beam.

The movement of the pushrod, through the interactions with the rocker, causes one of the vehicle's wheel to be raised (or lowered). The amount by which the wheel is raised (lowered) is therefore dependent on the triangular beam's deformation value. This phenomenon allows for driving over a small terrain obstacle without causing a movement of the differential mechanism. This leads to an uneven distribution of the rover's mass on its wheels, which worsens the traction properties, so this effect is not desired.

The amount of bending of the triangular beam was correlated with the height of the vehicle's wheels using an MDS analysis. The relationship found is shown in Fig. 8. It was determined that bending of the triangular beam measured using FEM corresponds to the wheel raising to a height of 6.33 mm.

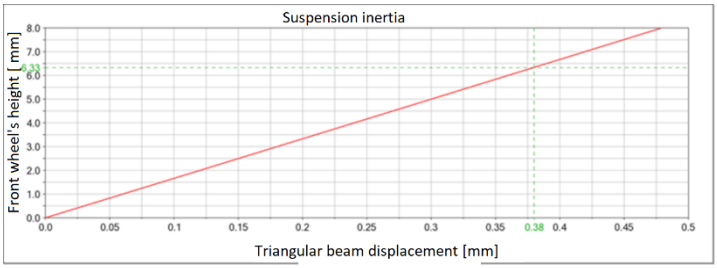


Fig. 8. Height of the front wheel depending on the triangular beam displacement

In the neutral position, which occurs during driving on a flat surface, the pushrod is positioned vertically. As a result of the suspension movement, the pushrod deviates from this position, leading to an increase in forces acting on this element. Pushrod's deviation from its neutral position is shown in Figure 9.

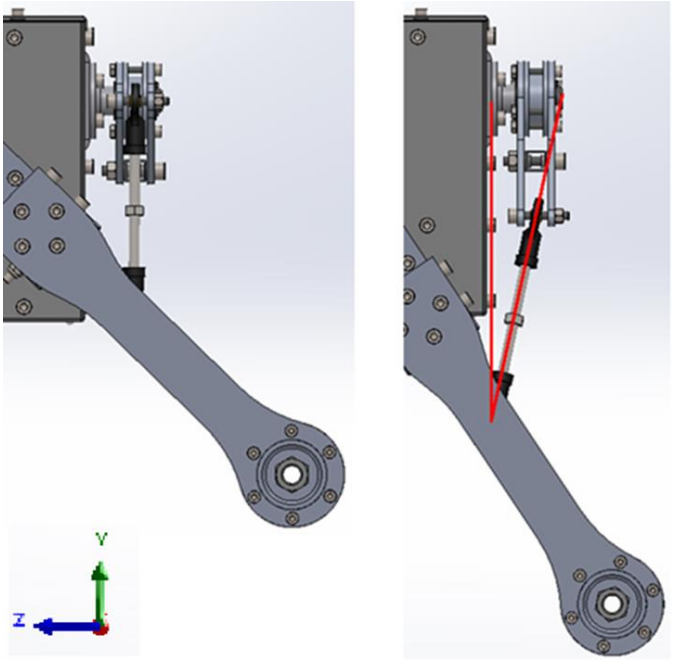


Fig. 9. Side view of the differential mechanism in different positions. On the left, the mechanism is in its neutral position. The pushrod is visible in a vertical position. On the right, the mechanism is shown while overcoming a terrain obstacle. The angle of inclination of the pushrod is shown in red.

The inclination of the pushrod resulting from a working suspension causes an increase in loads transferred through the mechanism in extreme positions (while climbing an obstacle with the maximum allowable height - for considered vehicle it is h = 300 mm). During the design phase of this new differential beam system, significant pushrod deviations from a vertical plane were noticed. Plot of the pushrod's inclination depending on the vehicle's wheel rise is shown in the chart in Figure 10.

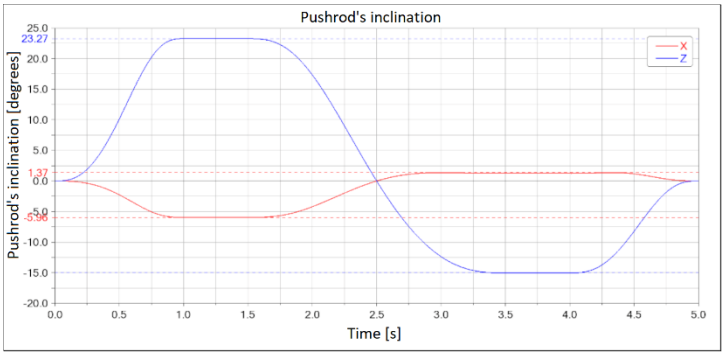


Fig. 10. Pushrod's inclination angle while overcoming uneven terrain with a height h = 300 mm. Angular displacements relative to the X and Z axes (coordinate system shown in Figure 9)

The described phenomenon is unfavourable, however, its severity is mild as long as loads in the neutral position (when driving on a flat surface) are reasonable low. Compared to Scorpio X, where the pushrod's deviation was no larger than 1.12°, in the new generation of rovers, this value is as high as 23.27°. This makes a 40.4 N force acting on the triangular beam in the neutral position increase to a maximum of 48.1 N while driving over an obstacle. Although the relative increase in force is rather large, due to the small load in the neutral position, the element stress is still acceptable. In comparison to the previous generation of this vehicle, an improvement has been achieved. In Scorpio X - despite a much more favourable pushrod's inclination - the maximum value of a force is as high as 207 N.

5. INFLUENCE OF THE NEW MOUNTING ON THE AMOUNT OF SPACE TAKEN BY THE SUSPENSION SYSTEM

Due to the vertical orientation of the differential mechanism's plane of movement, there is no possibility for a collision with the rover's frame. The new mounting method allowed for a very unrestrained design of the system's kinematics. It was possible to formulate the critical dimensions so as to minimise forces and loads transmitted via the mechanism. This denotes a better optimisation of the individual elements composing the differential mechanism, i.e. reducing their mass or increasing

their rigidity, which is indirectly an outcome of changes in the orientation of the differential system to the vertical one.

In Scorpio X, massive bearings located in the middle of the frame's beam were used. In Scorpio 7 they were replaced by the two smaller bearing systems located closer to the ends of the beam.

The dimensions of a single bearing assembly are important due to the need to leave as much space inside the rover's body as possible for arranging the vehicle's onboard electronics. Using mounts with smaller sizes, even in larger quantities, makes it easier to lay out the internal components of a rover. The amount of space occupied by the suspension system outside a rover's body has also decreased. Total volume is now 2.9 dm^3, which is 24% of the space occupied by the same system in Scorpio X. The space occupied by the Scorpio 7 suspension in its full range of motion is marked in red on Figure 11.

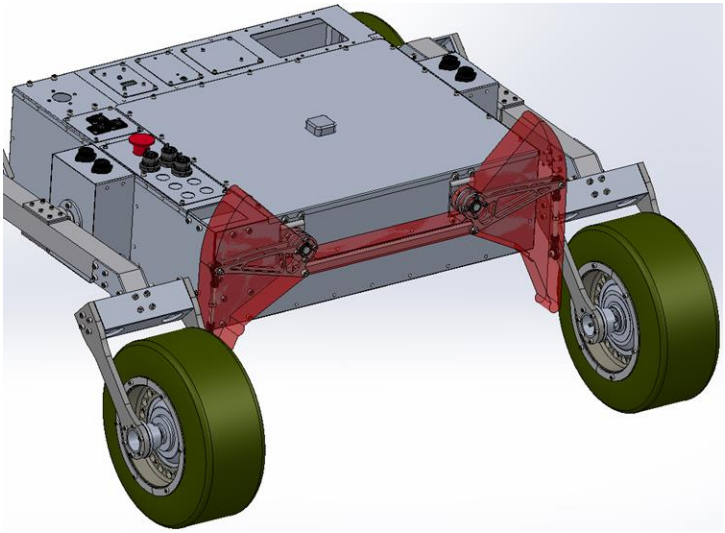


Fig. 11. Space required to allow movement of the suspension differential mechanism

6. ANALYSIS OF LOADS IN THE ROVER'S FRAME

Moving the mounting points of the differential system away from each other has a significant impact on the load carrying capability of the vehicle frame. Some of the rover's components are mounted to that frame, so it must be rigid to provide stable operating conditions for the vehicle. Displacements present in the frame decrease the suspension's rigidity, similarly as was the case for displacements in the differential mechanism. Changing the locations of the suspension's mounting points reduces the

magnitude of displacement in the frame beam. The concept of a load distribution's influence on a deflection magnitude present in the beam is shown in Figure 12.

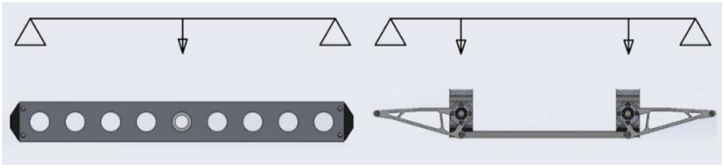


Fig. 12. Comparison of loads acting on the frame beams of Scorpio X (left) and Scorpio 7 (right) rovers. The distribution of loads in Scorpio 7 suspension leads to a smaller beam deflection value.

The frame was made out of square cross-section beams with dimensions of 20x20x1.5 mm and 15x15x1.5 mm. Additionally, in order to reduce weight, the frame's side panels were made as a cut-out lattice from a 3 mm thick sheet, whereas places intended to mount the rockers – from sheets with a thickness of 4 mm. These elements were made from 6060 aluminium due to the substantial strength-to-density ratio of this material.

In order to determine the magnitude of deflections in the frame's beams, FEM simulation was carried out in SolidWorks. Calculation parameters were determined based on the MDS analysis using MSC Adams software. Boundary conditions for the simulation are:

- Fixed displacement at the locations in which the frame attaches to the rockers;
- Triaxial stress acting on the differential mechanism's mounts. The applied forces are as follows: 500 N in the X axis, 30 N in the Y axis and 15 N in the Z axis.

A mesh built with the TETRA 10 elements, with a maximum edge length of 1 mm, was used. The results obtained are shown in Figure 13.

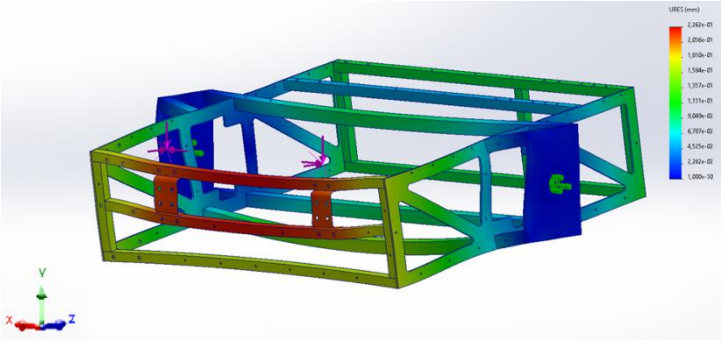


Fig. 13. Map of displacements of the loaded Scorpio 7 frame.

The maximum deflection was observed at the triangular beams attachment points, which was 0.22 mm. Compared to the Scorpio X frame, in which deflection reached

0.9 mm, a significant improvement was achieved. It is worth noting that due to the construction of the new frame, displacement at the attachment points of the differential mechanism includes displacement resulting from twisting the frame at the rockers' attachment points. This effect is responsible for the apparent increase in measured value by about 0.15 mm. This phenomenon did not occur in the Scorpio X frame.

7. ROVER'S WEIGHT

The Scorpio 7 rover weighs 48 kg, which is more than its predecessor. This difference is largely due to increased frame dimensions and is not directly related to the suspension system.

The suspension system itself weighs 4.9 kg, which is 10.2% of the rover's gross weight, while the differential mechanism weighs 0.47 kg, which is 1.0% of the rover's weight. In Scorpio X, the suspension weighed 4.5 kg (10.0% of the rover's weight), and the differential mechanism weighed 0.53 kg (1.2% of the rover). The increased weight of the new vehicle's suspension is mainly caused by its enlarged dimensions (both the length and width of the frame have been extended), which requires the use of longer rockers. However, considering the weights of only the differential mechanisms, it can be inferred that the reduction in mass of this system through shape and dimensional optimisations had been achieved, despite increased track width.

8. COMPARISON OF THE SCORPIO X AND SCORPIO 7 SUSPENSION SYSTEMS' PARAMETERS

Evaluation of vehicle's improvements is only possible by comparing the values that describe both the old and new generations of the rover. The following table (Table 1) shows parameters describing the Scorpio X and Scorpio 7 suspension systems. All angular values are given for overcoming a terrain obstacle of height h = 300 mm, which is the most demanding in terms of the stress experienced by the system. Despite the same requirements concerning maximum obstacle height for both rovers, the extended length of the Scorpio 7 rockers results in a decrease in their maximum angle of attack.

Tab. 1. List of parameters characterising the suspension systems of Scorpio X and Scorpio 7

Parameter	Scorpio X	Scorpio 7
Suspension system weight	4.5 kg	4.9 kg
Suspension system weight (excluding rockers)	530 g	470 g

Parameter	Scorpio X	Scorpio 7
Maximum frame deflection	0.9 mm	0.25 mm
Space occupied	12.1 dm^3	2.9 dm^3
Inclination of pushrods	1.2°	23.3°
Angle of attack of rockers	26.6°	20.8°

9. SUMMARY AND CONCLUSIONS

The modifications introduced have improved the parameters characterising the Scorpio 7 suspension system. A redesign of the differential mechanism reduced its weight while maintaining its full range of motion. The amount of space occupied both inside and outside the rover's body has decreased as well. Unfortunately, due to other changes not related to the suspension system, this weight abatement did not directly translate into a reduction in the overall weight of the vehicle. Compared to its predecessor, the new solution also features increased rigidity. In light of the above, the Authors consider the design of the Scorpio 7 rover a success.

REFERENCES

[1] KRZEMIŃSKI A., KOSOBUDZKI M., *Wstępna analiza wymagań stawianych kołom jezdnym do pojazdu wysokiej mobilności*, Journal of Translogistics, 2020, Tom Vol. 6 (16), 1.
[2] KRZEMIŃSKI, A., KOSOBUDZKI M., *Projekt koła wykonanego w technologii przyrostowej do pojazdu wysokiej mobilności*, Journal of TransLogistics, t. 7, nr 1, Politechnika Wrocławska. Oficyna Wydawnicza Politechniki Wrocławskiej, 2021, s. 19—38
[3] Regulamin zawodów Univeristy Rover Challenge https://urc.marssociety.org/home/requirements-guidelines (dostęp 26.10.2022 r.)
[4] KOSOBUDZKI M., ŁAZIK P., *Adaptation of the ROS system to control the Scorpio autonomous vehicle*, https:/doi.org/10.37190/JoT2022_05
[5] Informacje prasowe na temat misji Mars 2020, Mars 2020 Perseverance Launch Press Kit, 2020, https://www.jpl.nasa.gov/news/press_kits/mars_2020/download/mars_2020_launch_press_kit.pdf (dostęp z dnia 1.12.2022 r.)
[6] LOREK B., BERNAT R., KOSOBUDZKI M., *Analysis of the structure and operation of the Scorpio X rover suspension system*, https:/doi.org/10.37190/JoT2022_04
[7] SANDIN P. E., *Robot Mechanism and Mechanical Devices Illustrated*, 2003
[8] RUSIŃSKI E., CZMOCHOWSKI J., SMOLNICKI T., *Zaawansowana metoda elementów skończonych w konstrukcjach nośnych*, Oficyna Wyd. PWr, Wrocław, 2000
[9] MILLER S., *Teoria maszyn i mechanizmów. Analiza układów mechanicznych*, Oficyna wydawnicza PWr. Wrocław, 1996
[10] MCCONVILLE J., *Introduction to Mechanical System Simulation Using Adams*, 2015

Corresponding author:
Bartłomiej Lorek, bartek.lorek2@gmail.com

DOI: 10.37190/JoT2023_03

Wiktoria KULASZEWSKA, Julia KOSIEK*

ANALIZA TECHNOLOGII ON-SHORE POWER SUPPLY

Słowa kluczowe: *zielony transport, OPS, on-shore power supply, elektryka, porty*

OnShore Power Supply (OPS), czyli tzw. „zasilanie lądowe", umożliwia statkom otrzymywanie energii elektrycznej z lokalnej sieci. Korzystając z tej alternatywy, zanieczyszczenie środowiska jest zmniejszone, ponieważ pokładowy generator diesla może zostać wyłączony. Technologia ta, jest wykorzystywana od wielu lat, lecz dopiero teraz zdobywa uznanie.

W artykule dokonano analizy OPS. W części teoretycznej przedstawiono czym jest ta technologia i jaka jest budowa urządzeń zasilania lądowego. W części badawczej wykorzystano studium przypadku oraz analizę SWOT, która pozwoliła na wyróżnienie mocnych i słabych stron opisywanej technologii.

1. WSTĘP

Porty są nie tylko punktami węzłowymi w globalnych łańcuchach dostaw, ale jednocześnie są punktami koncentracji emisji zanieczyszczeń do powietrza. Statki, które manewrują w estuariach i w obrębie obszarów portowych oraz statki zacumowane, w dużym stopniu przyczyniają się do ogólnego zanieczyszczenia powietrza w miastach portowych. W ten sposób wysiłki na rzecz zmniejszenia tych emisji pozostawiono nie tylko samym liniom żeglugowym, ale także władzom portowym, operatorom portów i miastom portowym. Jedną z opcji, która w ostatnim czasie cieszy się ogromnym zainteresowaniem politycznym, jest zasilanie lądowe, tzw. Onshore power supply (OPS) [1]. Gdyby wszystkie statki wyłączyły silniki pomocnicze i zamiast tego zostały podłączone do lądowej energii elektrycznej, wpływ na środowisko byłby znaczący na całym świecie. Wykorzystując energię elektryczną z lądu, silnik pomocniczy może zostać wyłączony, co znacznie zmniejsza hałas i emisję dwutlenku węgla, tlenku siarki i tlenku azotu. Niektóre z korzyści to:

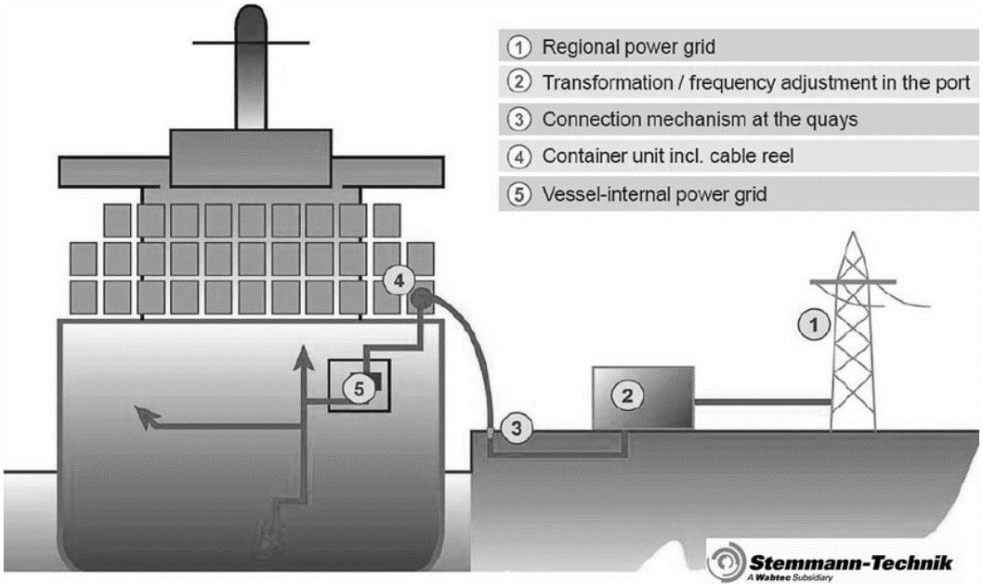
- Mniej emisji
- Mniej hałasu
- Mniejsze koszty
- Lepsze środowisko pracy na pokładzie.[1]

* Department of Navigation, Gdynia Maritime University.

Artykuł został sporządzony metodą studium przypadku oraz analizy SWOT. Ma on na celu przeanalizowanie technologii OPS, jej budowy, zastosowania, a także wskazania jej silnych i słabszych stron.

1.1. BUDOWA SYSTEMU OPS

Instalacja technologii OPS zazwyczaj wymaga budynku lub schronu, zawierającego niezbędny sprzęt techniczny. Plan budowy OPS uzależniony jest od typu statku zawijającego do portu, napięcia i częstotliwości morskich urządzeń elektrycznych oraz zasilania terminalu. W większości regionów i krajów częstotliwość zasilania i sprzętu elektrycznego wynosi 50 Hz, w niektóre 60 Hz, natomiast częstotliwość elektryczna większości statków wynosi 60 Hz. W przypadku statków śródlądowych i przybrzeżnych częstotliwość elektryczna wynosi 50 Hz [4]. Rys.1 przedstawia schematyczny układ stałego systemu OPS na przykładzie statku kontenerowego.



Rys. 1. Schematyczne przedstawienie stałego systemu OPS [1]
Fig. 1. Schematic representation of a fixed OPS-system [1]

„Istnieją dwa ogólne typy stałych systemów OPS. Ich główne zróżnicowanie polega na pytaniu, czy istnieje bezpośrednie połączenie z całą publiczną siecią elektroenergetyczną, czy też produkcja energii odbywa się niezależnie (najlepiej ze źródeł odnawialnych) za pomocą inteligentnej mikrosieci lądowej. Główną zaletą stałej instalacji OPS połączonej z całą siecią jest stabilność dostaw energii. Jednak, gdy energia jest wytwarzana z odnawialnych źródeł energii, to opcja ta jest najbardziej

korzystna. Wyzwania techniczne to łączność kablowa, zwłaszcza przy nabrzeżach o dużym zasięgu pływów. Często wymaga to zastosowania dodatkowych koryt i szybów kablowych, ramion dźwigów, platform podnoszących, systemów zarządzania kablami i tak dalej. Ponadto, w zależności od przepustowości sieci portowej i wymaganej dodatkowej przepustowości OPS, mogą wystąpić dodatkowe inwestycje w podstacje i niezbędne nowe kable" [1,2].

2. STUDIUM PRZYPADKU

2.1. PORT W GÖTEBORGU

Port w Goteborgu leżący w Szwecji, jest największym portem w krajach skandynawskich. Jego historia sięga aż 1620 roku. Rocznie zawija do niego ponad 11 tysięcy statków dostarczających ilość towarów zgodnie z tabelą 1. Obsługuje blisko 30% handlu zagranicznego kraju. Port znajduje się po obu stronach ujścia rzeki Göta älv. Północny brzeg, Norra Ęlvstranden, znajduje się na wyspie Hisingen, a południowy, Södra Ęlvstranden, na stałym lądzie. Położenie geograficzne portu sprawia, że w promieniu 500 km znajduje się 70% przemysłu i populacji Skandynawii. Posiada terminale kontenerowe, ro-ro, samochodowe, pasażerskie oraz naftowe i energetyczne.[15] Port w Göteborgu w liczbach:

Tab. 1. Przeładunki w porcie w Göteborgu,
źródło: opracowanie na podstawie danych z oficjalnej strony portu [14]
Tab. 1. Reloading at the Port of Gothenburg,
source: compilation based on data from the official port website [14]

Kontenery	776 000 TEU
Ro-Ro	515 000
Samochody	234 000
Pasażerowie	590 000
Energia	21,6 mln ton

W kwestii zastosowania systemu Onshore Power Supply, Port w Göteborgu jest najważniejszym punktem. To właśnie tutaj pierwszy statek w historii został podłączony do instalacji lądowej. Było to w 2000 roku i właśnie wtedy Port w Göteborgu stał się prekursorem tej technologii, która z resztą została przez niego opracowana w współpracy z armatorem Cobelfret oraz firmą ABB. Była to odpowiedź na potrzeby największego ówcześnie klienta portu – koncernu Stora Enso. [7] Jeszcze wcześniej, bo od 1989 roku port oferował energię elektryczną niskiego napięcia z lądu dla statków pasażerskich i Ro-Ro. Z tej usługi korzystają między innymi statki linii Stena Line. Od 2000 roku liczba urządzeń rosła z roku na rok. Średnio jedna

trzecia zawinięć statków ma obecnie dostęp do OPS. Poniżej udział procentowy statków, które są podłączane do zasilania lądowego.

Tab. 2. Udział procentowy statków, które są podłączane do zasilania lądowego, źródło: opracowanie własne na podstawie [11]
Tab. 2. Percentage of ships that are connected to shore power, source: compiled on the basis of the [11]

2016	2017	2018	2019	2020
35%	35%	34%	38%	34%

Port w Göteborgu ma wieloletnie doświadczenie w dostarczaniu energii z lądu oraz ciągle pracuje nad zwiększeniem liczby statków, które podczas cumowania wyłączają silniki i przechodzą na zasilanie lądowe. Najnowsza jednostka OPS została zainstalowana w terminalu Ro-Ro i rozpoczęła swoją działalność w styczniu 2021. Dodatkowo trwają prace nad powstaniem systemu o poziomie napięcia 6,6 kV, 50 Hz w terminalu energetycznym. Projekt ten jest wyjątkowy ze względu na to, że Port w Göteborgu byłby pierwszym portem na świecie, gdzie zastosowano tą technologię w obszarze niebezpiecznym. Wdrożenie zaplanowano na 2022 rok. Roczną redukcję emisji CO2 po instalacji systemu szacuję się na 2100 ton.[8] Ponadto zarząd oferuje szereg zachęt finansowych, aby skłonić statki do podłączenia się do OPS. Nie ma opłaty za dostarczoną energię, co więcej, statki uzyskują wyższe wyniki w indeksach, na których opiera się opłata portowa uwzględniająca rabat środowiskowy. Dzięki prężnie działającemu portowi w Göteborgu w rozwoju technologii Onshore Power Supply, w Szwecji podatek od energii został znacząco obniżony i wynosi on obecnie 0,5 korony szwedzkiej za kilowatogodzinę. [9]

2.2. PORT HAMBURG

Port w Hamburgu jest portem morsko-rzecznym leżącym w Niemczech. Położony jest między Morzem Północnym a Morzem Bałtyckim. Jest łatwo dostępny od strony Morza Północnego przez Łabę. Kanał Kiloński łączy port ze Skandynawią i całym regionem Morza Bałtyckiego. Taka lokalizacja sprawia, że Port w Hamburgu jest wiodącym ośrodkiem handlu zagranicznego Niemiec. Jego powierzchnia to aż 7200 hektarów. Posiada terminale kontenerowe, różnego przeznaczenia, masowe oraz wycieczkowe. Wyniki przeładunkowe tego portu są imponujące: 130 mln ton oraz 8,7 mln TEU. [10]

W tym przypadku, inwestycje związane z instalacją systemów Onshore Power Supply są mocno wspierane przez samo miasto Hamburg, które jest bardzo nastawione na trwałą poprawę jakości powietrza. Kontenerowce oraz statki wycieczkowe są zaopatrywane w energię neutralną pod względem emisji CO2 z publicznej sieci energetycznej. Ponadto energia ta pozyskiwana jest jedynie ze źródeł odnawialnych. [11] Wizją samego portu w Hamburgu jest stanie się całkowicie neutralnym portem

pod względem emisji CO2 do roku 2040. Wykorzystywanie OPS jest kluczowym działaniem w tej kwestii. Historia początków zastosowania tej technologii sięga 2015 roku. Wtedy to zarząd portu w Hamburgu zlecił firmie Siemens dostarczenie gotowych systemów OPS. Instalacja ta o mocy 12 megawoltów jest pierwszym tego typu systemem w Europie. Jest bardzo innowacyjna, ponieważ oprogramowanie dostosowuje częstotliwość lokalnej sieci energetycznej do systemu elektrycznego statku. [12] Została uruchomiona w 2016 roku. Od kwietnia 2018 roku na terminalu wycieczkowym Portu w Hamburgu regularnie działa system Onshore Power Supply. Statek wycieczkowy AIDAsol w sezonie po zainstalowaniu OPS był zasilany z lądu dwanaście razy z czego dziewięć to były pełne ładowania. Ogólnie korzystanie z energii lądowej w Porcie Hamburg jest powszechne głównie wśród statków wycieczkowych, ale też wśród kontenerowców. To właśnie te typy jednostek mają stosunkowo najwyższe zużycie energii. Port Hamburg podobnie jak Port w Göteborgu stosuje zachęty finansowe do korzystania z technologii Onshore Power Supply dla operatorów statków. Opłaty portowe uwzględniają różne taryfy, które premiują statki, które są przyjazne środowisku. Według obliczeń portu, w ten sposób można zaoszczędzić nawet 3000 euro na statkach wycieczkowych i kontenerowych.[13] Oczekuję się, że do 2025 roku wszystkie zaplanowane instalacje OPS będą działały. Poniżej szacunkowa redukcja emisji różnych zanieczyszczeń, która zostanie osiągnięta dzięki działaniu OPS (przy około 400 zawinięciach rocznie):

Tab. 3. Szacunkowa redukcja emisji różnych zanieczyszczeń, która zostanie osiągnięta dzięki OPS, źródło: opracowanie na podstawie [6]
Tab. 3. Estimated reduction of emissions of various pollutants that will be achieved thanks to OPS, source: compilation based on data obtained from [6]

Tlenek azotu NO_x	383 tony
Tlenek siarki SO_x	11 ton
Drobne cząstki stałe (PM 2,5)	2 tony
Dwutlenek węgla CO^2	30 000 ton

3. ANALIZA SWOT

Analiza SWOT jest kompleksową i szczegółową techniką planowania strategicznego i dogłębnej analizy danego przypadku. Ma ona również na celu prawidłowe porządkowanie informacji w badanym zakresie. [3] Rozwinięcie SWOT jest następujące – S – Strenghts, W – Weakness, O – Opportunities, T – Threats. Jest bardzo popularną metodą. W początkowych etapach analizy strategicznej okazuje się być uniwersalnym i prostym narzędziem. Jej podstawą jest odpowiednie zrozumienie kategorii czynników SWOT:

a) Wewnętrzne:
– pozytywne – mocne strony – Strenghts,
– negatywne – słabe strony – Weakness
b) Zewnętrzne:
– pozytywne – szanse – Opportunities,
– negatywne – zagrożenia – Threats.[5]

3.1. WEWNĘTRZNE CZYNNIKI ANALIZY SWOT SYSTEMU ONSHORE POWER SUPPLY

Mocne strony	Słabe strony
– Zmniejsza emisję spalin, hałas i wibrację ze statków w porcie, – Staje się coraz popularniejszy, a więc skutki korzystania z tego systemu będą szybciej widoczne, – Działa na rzecz ochrony środowiska, – Obniża koszty portowe dla firm spedycyjnych i armatorów.	– Wymaga równoległych inwestycji zarówno w porcie jak i w statkach, – Korzyści dla środowiska zależą od lokalizacji, – Koszty instalacji. – Produkcja energii ze spalania – sprawia to, że mamy jedynie zmianę miejsca emisji związków szkodliwych.

3.2. ZEWNĘTRZNE CZYNNIKI ANALIZY SWOT SYSTEMU ONSHORE POWER SUPPLY.

Szanse	Zagrożenia
– Ustanowienie globalnego limitu siarki, – Branża żeglugi morskiej zmierza do dekarbonizacji, – Polityka UE wymaga, aby porty w sieci TEN-T korzystały z tej technologii, – Wzrastająca ilość statków elektrycznych lub hybrydowych.	– Inne technologie jak np. systemy LNG, – Koszty energii elektrycznej.

System Onshore Power Supply to przyszłość każdego rozwijającego się portu morskiego. Teraz, kiedy ochrona środowiska jest jednym z najważniejszych elementów prowadzenia działalności, technologia ta ma duże szanse na rozwój. Dodatkowo polityka UE wymaga, aby porty w sieci TEN-T korzystały z tego rozwiązania. Niestety koszty instalacji są wysokie, a w dodatku wymagane są inwestycje zarówno w porcie jak i w statkach. Wzrastające koszty energii elektrycznej sprawiają, że często nie opłaca się korzystać z tej technologii. Mimo wszystko Onshore Power Supply staje się coraz popularniejszy i na pewno instalacja tego systemu podnosi konkurencyjność portu i pozytywnie wpływa na środowisko.

4. PODSUMOWANIE

System Onshore Power Supply znany i stosowany od kilkunastu lat, dopiero teraz nabiera coraz większego znaczenia ze względów ekologicznych. W czasach, kiedy globalne ocieplenie postępuje należy jak najszybciej zredukować emisję gazów cieplarnianych. Odpowiedzią na to jest właśnie między innymi OPS. Niestety jest to inwestycja, która jest droga oraz wymaga innych działań, aby mogła odpowiednio spełniać swoją rolę. Mimo tego ma więcej zalet niż wad i jest bardzo ważnym narzędziem w działaniach dotyczących szeroko pojętej ochronie środowiska. Ponadto zastosowanie Onshore Power Supply świadczy o innowacyjności i otwartości na postęp portów i potencjalnych jednostek, które będą korzystać z tego systemu. Dzięki takim przekonaniom jest on też bardziej popularny, co przekłada się na większy wkład ludzi w redukcję emisji spalin. Przejście na OPS oznacza w praktyce 100% redukcję wszystkich emisji, które byłyby generowane przez pokładową generację energii przy użyciu paliwa MGO lub MDO [6]. Celem artykułu było zdefiniowanie i przedstawienie za pomocą metody studium przypadku technologii OPS oraz analiza słabych i mocnych stron wprowadzenia takiego rozwiązania. Cel ten udało się zrealizować.

LITERATURA

[1] Czermanski E., Kramer I., Onshore power one option to reduce air emissions in ports, Springer, 2020.
[2] Czermanski E., Morska żegluga kontenerowa a zrównoważony rozwój transportu, Uniwersytet Gdański, Gdańsk, 2019.
[3] Klimek H., Strategia rozwoju polskich portów morskich, Studia Gdańskie. Wizje i rzeczywistość 5, 225-244, 2008
[4] Kun Li and Ke Du, Research on Onshore Power Supply System in Port for Ships, 2020 IOP Conf. Ser.: Earth Environ. Sci. 558 052022.
[5] Szałata Ł., Zwoździak J., Analiza SWOT jako podstawowe narzędzie w zarządzaniu środowiskiem. Politechnika Wrocławska, 2011
[6] Walker TR et al (2018) Environmental effects of marine transporta-tion. In World Seas: An Environmental Evaluation, 2nd ed, Vol. 3: Ecological Issues and Environmental Impacts, p 505–530. ISBN978-0-12-805052-1. Elsevier Ltd. https://doi.org/10.1016/C2015-0-04336-2
[7] Zeszyty naukowe nr 741, Europejska przestrzeń transportu wyzwania rynkowe. Uniwersytet Szczeciński, 2012, Szczecin
[8] https://sustainableworldports.org/project/port-of-gothenburg-frontrunner-on-onshore-power-supply-for-vessels/ (data dostępu: 11.04.2022)
[9] https://www.portofgothenburg.com/about-the-port/greener-transport/onshore-power-supply-for-vessels/ (data dostępu: 11.04.2022)
[10] https://www.hafen-hamburg.de/en/portofhamburg/port-of-hamburg/ (data dostępu: 10.04.2022)
[11] https://sustainableworldports.org/project/port-of-hamburg-onshore-power-supply-ops/ (data dostępu: 09.04.2022)
[12] https://www.offshore-energy.biz/hamburg-port-pioneers-onshore-power-supply-for-cruise-ships/

[13] https://www.hamburg-port-authority.de/en/themenseiten/lng-shoreside-power (data dostępu: 11.04.2022)
[14] https://www.portofgothenburg.com/ (data dostępu: 12.04.2022)
[15] https://www.portofgothenburg.com/about-the-port/history-of-the-port/ (data dostępu: 11.04.2022)

ANALYSIS OF ON-SHORE POWER SUPPLY TECHNOLOGY

Key words*: green transport, OPS, on-shore power supply, electricity ports*

OnShore Power Supply (OPS), i.e. "shore power" enables ships to receive electricity from the local grid. By using this alternative, pollution is reduced as the on-board diesel generator can be turned off. This technology has been used for many years, but is only now gaining recognition.

The article analyzes OPS. The theoretical part presents what this technology is and what is the construction of shore power devices. In the research part, a case study and SWOT analysis were used, which allowed to distinguish the strengths and weaknesses of the described technology.

Corresponding author:
e-mail: juliakosiek@op.pl

DOI: 10.37190/JoT2023_04

Konrad CYPRYCH , Michał Jan WNUK*

MOBILE RAMAN SPECTROMETRY ON SCORPIO 7 ROVER

Keywords: *Martian rover, Raman spectrometry, OFF-ROAD Scientific Association, Scorpio 7, University Rover Challenge.*

This article describes the design of the mobile Raman spectrometer of the Scorpio 7 rover. It was constructed to study the organic content of soil samples taken during the Rover Challenge series of Mars rover competitions. The basic theoretical issues that are used in Raman spectroscopy are described. Design assumptions and requirements for the construction and control software of the spectrometer during its use on board the Scorpio 7 Mars rover, constructed by the OFF-ROAD Scientific Association at the Wroclaw University of Technology, are discussed. Measurements of Raman spectra carried out by the Raman spectrometer installed in the research module of the Scorpio 7 rover are presented.

1. INTRODUCTION

Raman spectroscopy (RS) is a spectral analysis technique that utilizes inelastic scattering to obtain information about the material being studied, specifically its vibrational states [3]. This is achieved by exposing the material to intense monochromatic light, typically a laser, and analyzing the resulting spectrum. RS has gained widespread application in various fields of science and everyday life due to its ability to examine solid samples without the need for prior purification and the potential for miniaturization for portable systems [1]. Modified Raman spectrometers are particularly used in biological research as they have minimal interference with water, allowing the study of biological samples in their natural state [9]. Additionally, RS techniques are employed as an analytical method in medicine, the pharmaceutical industry, environmental protection, archaeology, geology, customs protection, and quality control of food products [1].

The Raman spectrometer was constructed by students of the OFF-ROAD Unconventional Vehicles Scientific Circle operating at the Department of Fundamentals of Mechanical Engineering and Mechatronic Systems, Wroclaw University of Technology. The aim of building this analytical device was to increase

* Wroclaw University of Science and Technology

the research capabilities of the Scorpio 7 Mars rover during its participation in the Rover Challenge series. The main task of the constructed Raman spectrometer is to examine soil samples collected by the Scorpio 7 rover for biomarkers. By identifying these organic compounds, it is possible to correctly determine whether active life forms are, or have been, present in the soil sample.

The solutions used during the construction of the Raman spectrometer adapted for operation on the Scorpio 7 rover can be used to conduct chemical analysis in hazardous conditions for humans. A potential avenue for the development of this technology is the modification of the spectrometer to a SORS-type system, which would allow remote chemical composition analysis of unidentified chemicals without the need to open their containers [13].

The currently constructed system could be used to conduct autonomous chemical composition studies of contaminated areas without the need for a large number of qualified personnel.

2. RAMAN SCATTERING [2]

Raman scattering involves the interaction of a photon of a specific energy with the electron density of a chemical bond present in the molecule under study. This

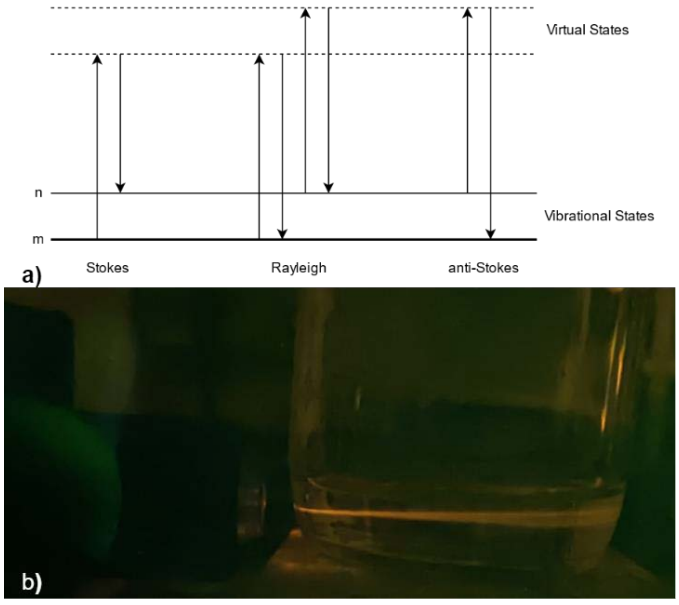


Fig. 1 Representation of Raman Scattering a) Simplified Jablonski diagram describing light scattering phenomena, b) Raman scattering from Tetrahydrofuran solution excited with laser light of 532nm, 50mW. Image acquired using 550nm long-pass filter.

interaction causes the electrons involved in the bond to be excited to a virtual state from which the electron returns to a lower excited vibrational level resulting in a Stokes band. If the electron was at an excited vibrational level (due to, for example, an elevated ambient temperature) before the interaction with the photon, the interaction results in the electron being excited to a higher virtual state, from which it returns to the ground state, resulting in Anti-Stokes scattering. These phenomena can be represented graphically in the simplified Jablonski diagram shown in Figure 1a.

As a result of the interaction of the photon with the electrons present in the chemical bonds of the analyzed compound, the photon undergoes an inelastic scattering from the tested material and loses part of its original energy. As a result of the loss of part of its energy, the photon, when reflected from the sample, decreases its frequency, which is observed as a change in the color of the scattered light, as can be seen in Figure 1b for the tested Tetrahydrofuran solution.

3. MATERIALS AND METHODS

3.1. DESCRIPTION OF THE RAMAN SPECTROMETER

The Raman spectrometer consists of two optical systems: the excitation system and the spectrometer (Figure 2). The first part is responsible for generating a Raman signal in the sample. This effect is achieved by focusing monochromatic light, such

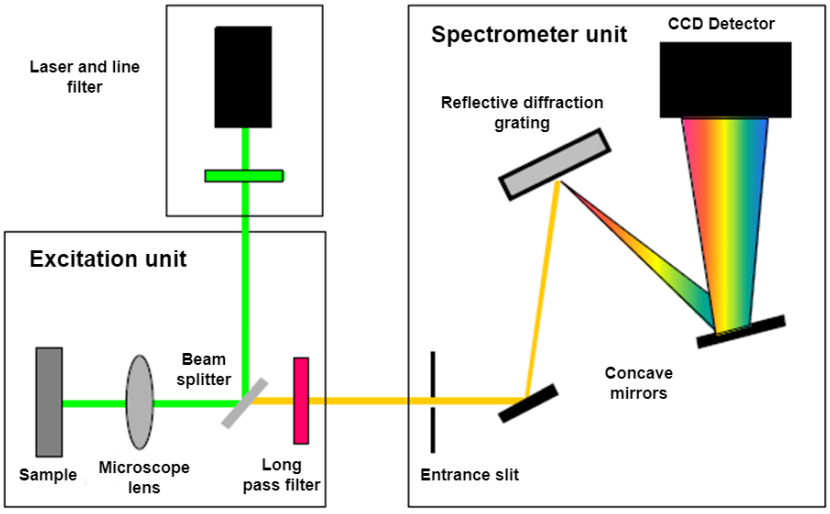


Fig. 2 Diagram of Raman spectrometer in a backscattering setup [8].

as a laser, on the surface of the tested material. The generated electromagnetic radiation is then filtered out of the Rayleigh scattering (excitation beam) using optical filters. The filtered radiation is then focused into the spectrometer using a set of focusing lenses. In the spectrometer, the signal is directed by a system of concave mirrors first to a reflective diffraction grating and then to a CCD array. On the surface of the diffraction grating, a single polychromatic beam is split into multiple monochromatic beams. The radiation is directed via another concave mirror to the surface of the CCD matrix, which converts the resulting spectral spectrum into digital information.

The design of the Raman spectrometer used on the Scorpio 7 rover was based on the basic assumptions outlined in the paragraph above. Due to the operating conditions of the spectrometer under construction, necessary modifications have been made to ensure optimal performance.

3.2. HOUSING

The housing for the Raman spectrometer used on the Scorpio 7 rover was made using additive manufacturing technology on 3D printers using FFF (Fused Filament Fabrication) technology, from PET-G type filament. This type of technology and material was chosen because of the low cost of fabricating customized structural components and the satisfactory strength-to-weight ratio.

3.3. EXCITATION UNIT

Due to the low intensity of Raman scattering obtained when testing solid samples, it was decided to use an excitation system in a backscattering-type setup. In this system, the excitation laser beam first is reflected from a dichroic mirror, which is positioned at an angle of 45 degrees to the laser beam (Figure 3b). This positioning of this mirror ensures that the excitation beam is directed directly at the tested sample. After the excitation beam reflects off the surface of the dichroic mirror, the excitation beam is focused by the microscope objective, which directs the excitation beam onto the sample.

This excitation system provides the least number of optical elements that are in the path of the generated Raman scattering, which returns via the same path as the excitation beam. Due to the dichroic properties of the mirror used to direct the excitation beam onto the sample, the generated Raman scattering passes through this optical element, where it is then directed into the spectrometer.

Due to the 50% efficiency of the selected dichroic mirror used in the constructed excitation system [5], it is necessary to use an additional optical filter to filter out residual Rayleigh scattering from the generated Raman scattering that has not been reflected by the dichroic mirror.

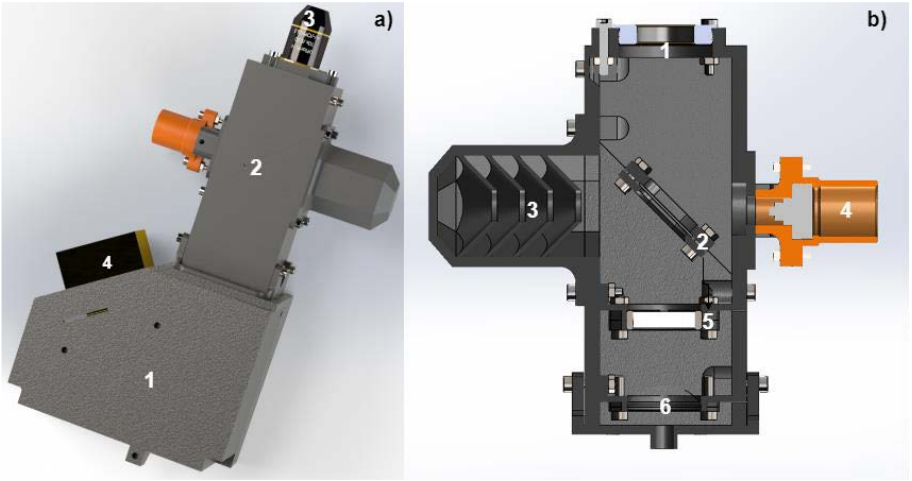


Fig. 3. 3D visualizations of constructed Raman Spectrometer
a) Scorpio's 7 Raman Spectrometer (1 – Spectrometer Unit, 2 – Excitation Unit, 3 – Microscope Objective, 4 – CCD array);
b) Cross-section of the Excitation Unit (1 – Objective Mount, 2 – Diffraction Mirror, 3 – Laser Light Trap, 4 – Laser Mount, 5 – Optical Filter, 6 – Focusing Lens).

3.4. SPECTROMETER UNIT

The optical system used in the Raman spectrometer under construction consists of five optical elements: an entrance slit, two focusing mirrors, a reflecting diffraction grating, and a CCD array (Figure 3a). Due to the focal lengths of the focusing mirrors used and the possible space for the Raman spectrometer inside the body of the Scorpio 7 rover, it was decided to use a modified optical distribution according to the Czerny-Turner layout [12]. In this arrangement, the analyzed radiation beam first passes through the entrance slit, which is located opposite the first of the focusing mirrors. This mirror directs the radiation beam from the slit to the reflecting surface of the diffraction grating. Once the beam is reflected and split on the surface of the grating, it falls on the surface of the second focusing mirror, which directs the split beam onto the surface of the CCD array.

The distances between the optical elements and their angular position concerning each other were first simulated and then optimized using numerical methods, to obtain the required resolution of the system for the observation of Raman spectra.

3.5. SCORPIO 7 ROVER

Scorpio 7 is a mobile research platform, modeled by its design on rovers that travel on the surfaces of Mars or the Moon. To move easily over rough terrain, the vehicle is equipped with a four-wheel differential suspension. The driving module of

the Scorpio 7 rover is a modified version of the rocker-boogie suspension used in NASA's Mars rovers (Perseverance or Curiosity).

The rocker arms of the constructed rover are connected by a differential mechanism that allows it to overcome obstacles up to 30 cm high. In addition to the driving module, the Scorpio 7 platform has a manipulator module, which has 6 degrees of freedom. This means that this manipulator is capable of movement in 6 different axes. The manipulator on this research platform can perform precision operations (Figure 4a), such as typing on a keyboard, and can take soil samples for testing using an interchangeable tip in the form of a small excavator bucket (Figure 4b). In addition, the Scorpio 7 mobile research platform carries 5 digital cameras, needed for precise control of the ride or manipulator. To maintain sufficient communications with the Scorpio 7 rover, radio and antenna masts have been installed on board, with radio systems operating at frequencies from 2.4 to 5.8 GHz.

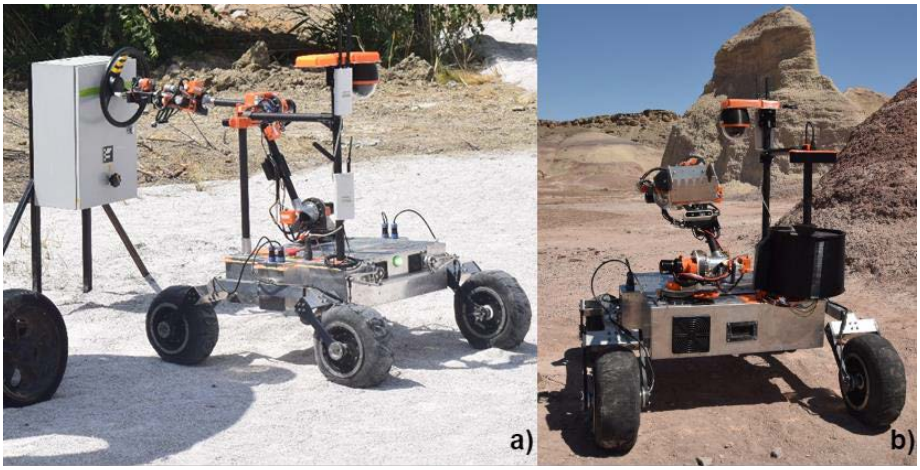


Fig. 4. Scorpio 7 Rover.
a) during the Anatolian Rover Challenge 2023 competition; b) with manipulator in digging configuration during the University Rover Challenge 2023 competition

3.6. RESEARCH MODULE DESCRIPTION

The research module located on the Scorpio 7 rover was prepared for the requirements of the 2023 University Rover Challenge, where it was required to detect the activity of living organisms in soil samples collected by the rover [6]. The module used consists of two main segments: analytical and storage. The main device of the analytical segment is a Raman spectrometer under construction, which allows the identification of organic compounds based on the Raman spectra obtained. A digital microscope has also been added to the segment for visual analysis of samples.

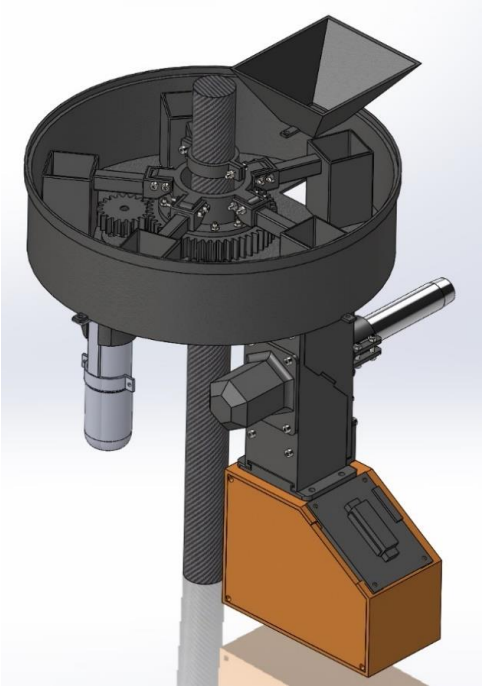


Fig. 5 Model of the storage segment of the Scorpio 7 rover's research module with connected Raman spectrometer

To analyze the soil samples collected by the analysis segment of the Scorpio 7 rover's research module, it is first necessary to store them in the rover's controlled environment - the storage segment (Figure 5). A rotating mechanism has been constructed, with 5 chambers with external dimensions of 33x33x55mm. Using this mechanism, it is possible to move a given chamber to 3 different locations: for analysis with a Raman spectrometer, for visual analysis with a digital microscope, and under the reception area of the collected soil sample. The bottom of these chambers is made of polymethylmethacrylate, due to the possibility of analysis with a Raman spectrometer and a digital microscope - both of which are mounted under the storage segment so that the bottom of the sample chambers can be observed.

3.7. READING DATA FROM THE RAMAN SPECTROMETER

According to the rules of the 2023 University Rover Challenge [6], all analysis of the collected soil samples had to take place on board the rover being operated. Thus, it was necessary to configure a server to provide a USB interface from the rover's on-board computer to the IP network, since the software and libraries

provided by the manufacturer of the CCD array support only Microsoft Windows family operating systems [4], which is not used in a mobile vehicle.

As a result, after connecting to the rover's Wi-Fi network and running the USB server client application, a computer at the base with Microsoft Windows installed was able to communicate with the array connected to the rover's onboard computer (Figure 6).

To read data from the CCD array, software was created using communication libraries provided by the manufacturer to retrieve data on the exposure intensity of each pixel of the array and visualize it in the form of graphs.

3.8. RAMAN SPECTROMETER SOFTWARE

To interpret the data, a software application was written in which the Raman spectra obtained during the spectrometer measurement are visualized. Basic functions were installed in the application to analyze Raman spectra, e.g.: modifying the signal integration time (the time the array collects the signal, increasing its intensity). In addition, an Asymmetric Least Squares (ALS) [11] measurement baseline estimation algorithm has been added to the application, which allows filtering out the fluorescence spectrum from the collected Raman spectrum (the resulting fluorescence spectrum has a much higher intensity than the Raman spectrum).

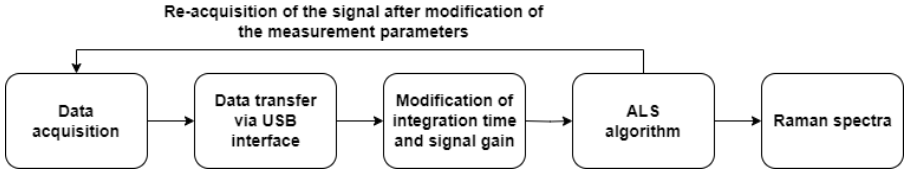


Fig. 6 Diagram of the process for obtaining a Raman spectrum from the Scorpio 7 rover's Raman spectrometer

4. RAMAN SPECTRUM MEASUREMENTS ON THE SCORPIO 7 ROVER

During the first test under the operating conditions of the Scorpio 7 rover, satisfactory Raman spectra were obtained from the constructed spectrometer. The measurements focused primarily on qualitative analysis of soil samples. Calibration and testing of the instrument were carried out using a pure THF solution (Figure 7) and soil samples with different percentages of spirulina (Figure 9), to simulate the presence of various organic substances in the soil sample under test.

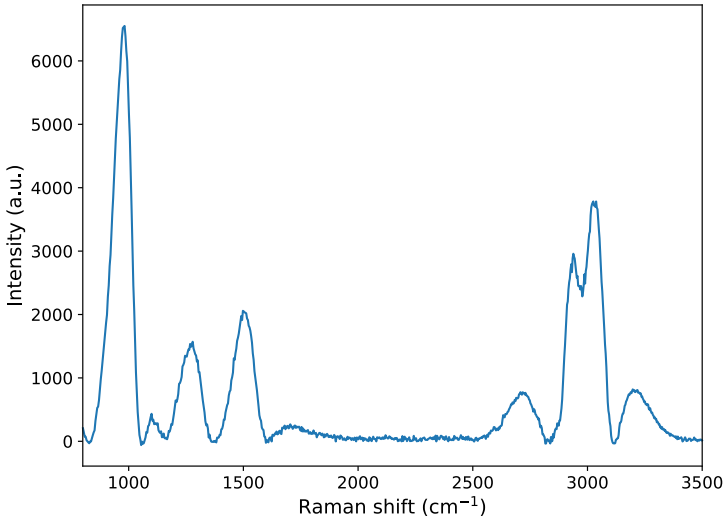


Fig. 7 Raman spectrum of THF solution obtained in the Raman spectrometer (532 nm; 50mW; Integration time: 0.4s)

The obtained Raman spectra were subjected to further data processing using an ALS-type algorithm. In the case of the study of solid samples, it was necessary to use this type of processing of the received data, because the received signal was characterized by very low intensity and there was a phenomenon of fluorescence of the sample, which prevented the analysis of the received data - the fluorescence spectrum "covered" the Raman spectrum of interest.

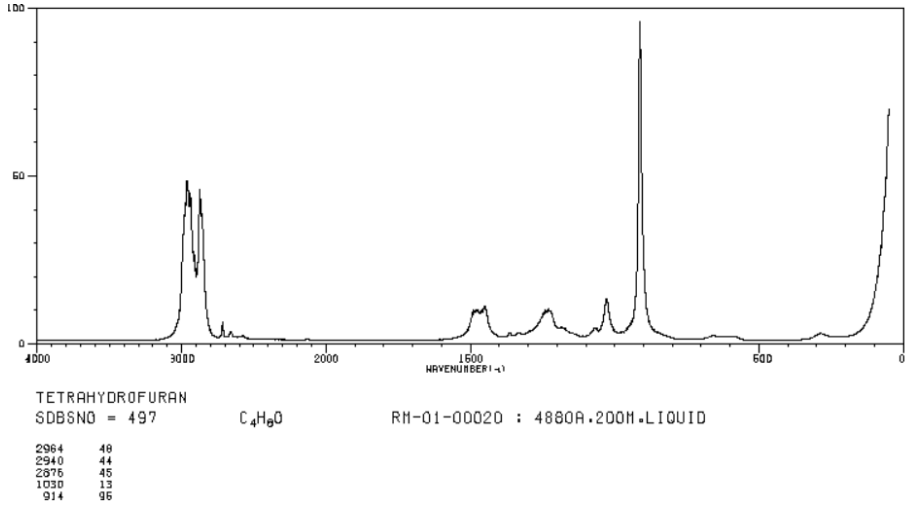


Fig. 8. Raman spectrum of THF solution obtained with 488 nm laser excitation [7].

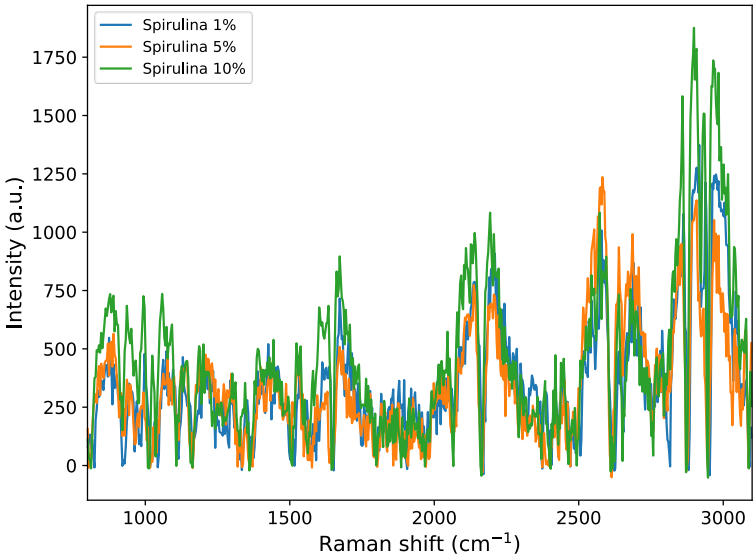


Fig. 9 Raman spectra obtained from soil samples containing spirulina at different weight concentrations (1%, 5%, and 10%) (532 nm; 50mW)

The main conclusions of the analyses were the presence of a wide range of organic substances contained in the sample with spirulina added. First of all, this is evidenced by the presence of intense peaks in the spectral region from 3150 - 3340 cm^{-1} [10]. Activity in this spectral region indicates the presence of the -NH bond, which is widely present in amino acids. In addition, the visible peaks of high intensity in the range from 700 - 1260 cm^{-1} testify to the presence of aliphatic and aromatic carbon bonds, which are widely present in organic compounds [10].

5. SUMMARY AND CONCLUSIONS

Implementing the Raman spectrometer under construction into the design of the Scorpio 7 rover made it possible to conduct chemical analysis of collected soil samples. Together with additional microscopic analysis in the research module of the Scorpio 7 rover, it significantly expanded the in-situ analysis capabilities of the unconventional vehicle of the OFF-ROAD Scientific Circle. After testing the operation of the spectrometer during the movement of the Scorpio 7 mobile research platform, the need to increase the stability of the Raman spectrometer in use was noted. The currently used system for recording Raman spectra requires a change in the used housing for optical components. The properties of the used 3D printing technology, which is characterized by anisotropic mechanical properties and the occurrence of material shrinkage, cause the used optics to be exposed to uncontrolled

displacement during shocks caused by the movement of the Scorpio 7 rover. The result of these displacements is the decalibration of the spectrometer, which significantly affects the veracity of the recorded Raman spectra.

After conducting a series of measurements with the constructed Raman spectrometer, the need to replace the used excitation source (532 nm laser, 50 mW) with a source of higher power was recognized, since the currently recorded Raman spectra are characterized by very low signal intensity. Too low a power of the used excitation may cause organic compounds to generate a less intense Raman scattering phenomenon that will not be observed by the used recording system.

Conclusions from the work of the current system will be taken into account in the next version of the Raman spectrometer.

LITERATURE

[1] NEETHU EMMANUELA, RAJI B, NAIR, BINI ABRAHAM AND KARTUVATH YOOSAF; *Fabricating a Low-Cost Raman Spectrometer to Introduce Students to Spectroscopy Basics and Applied Instrument Design*; J. Chem. Educ. 2021, 98, 2109-2116

[2] EWEN SMITH; *Modern Raman Spectroscopy – A Practical Approach*, Strathclyde University Glasgow; Geoffrey Dent, Intertek ASG and UMIST Manchester (2005); John Wiley & Sons. Ltd; ISBN 0-471-49794-0

[3] WAQAR AHMED AND MARK J; *Emerging Nanotechnologies for Manufacturing – A volume in Micro and Nano Technologies*; Second Edition (2015); ISBN 978-0-323-28990-0

[4] HAMAMATSU PHOTONICS K.K; *Driver circuit for CCD image sensor – C11860*, Solid State Division; Cat. no. KACC1232E08 Nov. 2022 DN

[5] THORLABS; *Technical documentation of the DMLP550R dichroic mirror*, https://www.thorlabs.com/newgrouppage9.cfm?objectgroup_id=3313&pn=DMLP550R (accessed 03.08.2023)

[6] *Rulebook of the University Rover Challenge 2023 competition*, https://urc.marssociety.org/home/requirements-guidelines (accessed 03.08.2023)

[7] K. TANABE AND J. HIRAISHI; *Spectral database of organic compounds – Raman Spectra*; National Institute of Advanced Industrial Science and Technology (AIST), Japan https://sdbs.db.aist.go.jp/sdbs/cgi-bin/cre_index.cgi (accessed 03.08.2023)

[8] *Backscattering Raman System*, PhysicsOpenLab (2022); https://physicsopenlab.org/2022/04/22/backscattering-raman-system/ (accessed 03.08.2023)

[9] SCHWARTZ T, JUNGFER C, HEIßLER S; *Combined use of molecular biology taxonomy, Raman spectrometry, and ESEM imaging to study natural biofilms grown on filter materials at waterworks*; Chemosphere (2009) 77(2) 249-257

[10] FRAN ADAR; *Introduction to Interpretation of Raman Spectra Using Database Searching and Functional Group Detection and Identification*; Spectroscopy-07-01-2016, Volume 31, Issue 7 Pages: 16–23

[11] *Adaptive Asymmetric Least Squares baseline estimation for analytical instruments*; Sergio Oller-Moreno ∗†‡, Antonio Pardo ‡, Juan Manuel Jimenez-Soto †‡, Josep Samitier ‡§ and Santiago Marco; †Signal and Information Processing for Sensing Systems, Institute for Bioengineering of Catalonia. Barcelona, Spain‡ Dept. Electronics, University of Barcelona, Barcelona, Spain § Nanobiotechnology, Institute for Bioengineering of Catalonia. Barcelona, Spain ; IEEE 2014

[12] KEN M. HARRISON; *Astronomical Spectroscopy for Amateurs* Cobham UK; Springer New York Dordrecht Heidelberg London (2011); ISBN 978-1-4419-7238-5
[13] RACHEL MCGEE, ANA BLANCO, OLIVER PRESLY, ROBERT J. STOKES, *Portable Spatially Offset Raman Spectroscopy for Rapid Hazardous Materials Detection Within Sealed Containers*; Spectroscopy-11-02-2018, Volume 33, Issue 11

Corresponding author:
synchem99@gmail.com

DOI: 10.37190/JoT2023_05

Grzegorz LESIUK*, Paweł ZIELONKA, Kayode OLALEYE,
Japhet SOOGABBE, Adrian Ferrer LAFARGA,

APPLICATION OF TAGUCHI METHODS (DOE) IN COMPOSITE ENGINEERING

Keywords: *composite, Taguchi method, flame retardant, epoxy resin*

In the paper, a design of experiment (DOE) in terms of the Taguchi method was used for the optimization of the manufacturing process. This approach makes it possible to do fewer experiments while still getting the desired outcomes. This research programme will use this tool to optimize the resin casting process by monitoring manufacturing parameters like temperature, curing time, and flame-retardant concentration. Thus, this study aims to determine the ideal set of parameters for the resin casting of composite materials. Based on experimental results, it was possible to find crucial factors and their influence on the fracture strength of resin for composite manufacturing systems.

1. INTRODUCTION TO DESIGN OF EXPERIMENTS – TAGUCHI METHOD

Thermosetting polymers cured with epoxy resins offer a wide range of uses due to their mechanical and physical characteristics; they are mostly used as matrix in advanced composites for automobile and aeronautical applications[1–4]. The following are some of these materials' primary characteristics: Outstanding adhesion to a wide range of substrates; (ii) excellent resistance to chemicals, especially in alkaline environments; (iv) minimal shrinkage; (v) beneficial electrical insulation properties; (vi) excellent corrosion resistance; and (vii) ability to cure over a wide temperature range are just a few of the material's many outstanding qualities [2–5]. Understanding the kinetics of epoxy resin curing can help you optimize composites' properties, reducing processing times, energy usage, expenses, and product quality [4–7]. Because it affects the final qualities of fabricated parts, the epoxy resin curing process is therefore the most important step in the manufacturing process. Epoxy resins undergo cross-linking or curing processes that create a three-dimensional infusible network by reacting hydroxyl groups or oxirane functional monomers. Both direct coupling of the resin molecules by a catalytic homopolymerization and

* Faculty of Mechanical Engineering, Wrocław University of Science and Technology.

coupling through an intermediate reactive known as a curing agent—compounds containing active hydrogen, such as polyamines, polyacids, polymercaptans, and polyphenols, to name a few—can cause the cross-linking process [3,4,8,9]. The reaction is extremely exothermic due to the high degree of reactivity of chemical species involved in the curing process; hence, the polymerization of epoxy resins must be carefully regulated to avoid the reaction heat being released from the process accelerating itself [2–4]. It has been shown that a number of analytical methods can be used to track the reaction's intensity and ascertain the epoxy resins' degree of curing [1–4,10–12]. Fourier-transform infrared spectroscopy (FTIR) is one of the direct methods that may be used to assess the concentration of one or more reactive groups over time (during the curing process). The main reasons FTIR is employed are its nondestructive approach, practicality, and adaptability. Additionally, in contrast to conventional characterization methods, this technique offers exceptional advantages.

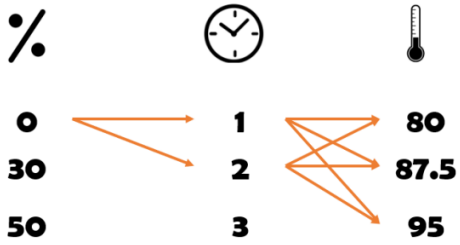


Figure 1. Taguchi method example

Applying many design of experiments (DOE), such as ANOVA, fuzzy logic, complete factorial design, response surface methodology (RSM), and the Taguchi technique, was necessary to optimise the FDM input parameters [13]. Taguchi's design of experiments technique was frequently used to optimise the FDM parameter setting due to its robustness, tolerance, and dimensional control [14]. Ahmad et al. [15] optimised the FDM printing parameters using the Taguchi technique to increase the surface roughness of the produced items. The Taguchi method, on the other hand, is a descriptive survey that pinpoints a process or product in order to improve its usability. The Taguchi technique is used because it is easy to use and a problem-solving method that can help enhance process performance and boost productivity. The strategy is called the test's factorial outline. For every trial, the level combination of information plan variables is chosen using the orthogonal technique [16]. Optimising a process's parameters to achieve maximum efficiency is Taguchi's main objective [17]. The FDM input parameters, including the printing pattern, printing speed, layer thickness, and raster orientation, were optimised using the Taguchi technique. The findings showed that at a 20° displacement angle, layer thickness significantly affected Young's modulus [18,19]. Tensile strength is increased and raw material is conserved when the

lowest layer thickness is used [40][20]. Five parameters' effects on the surface integrity of ABS parts made with FDM were examined by Kumar et al. [21,22]. In this work, the ideal set of parameters for the resin casting of composite materials was investigated using Taguchi technique as described above.

2. MATERIALS AND METHODS

The resin that was used for this purpose is epoxy resin, the most resistant adhesive used nowadays. Specifically, is the Biresin CR141, a resin that is prepared with the mixture of three different components, A symbolizes the resin, B the hardener, and C is the accelerator. The proportion of the components according to the manufacturer was not changed. According to the specification given, the proportions are 100 grams of A, 90 grams of B and 2 grams of C. The components A and B of the Biresin are contained in metallic barrels as the most part of the mixture is made by these components. The component C is given in a small quantity. The fiberglass was used for the reinforcement of concrete, for this reason is important that the resin be as non-flammable as possible as it is used in buildings. For this purpose, a flame retardant was added to the to the mixture. Having known this, the parameters in the process that were changed were three, so we had three factors in our Taguchi matrix. These parameters are as follow:

- Temperature: The resin, according to the manufacturer, must be cured 3 hours at 80 degrees, 3 hours at 120 degrees and 3 hours at 140 degrees. Then 139 degrees is the glass transition temperature of this resin, which is the temperature when a polymer goes between the rigid and a flexible state. For this reason, we used three combinations of temperatures based on the manufacturer sequence of temperatures. One combination would be 7.5 degrees more in each state, one with the manufacturing temperature and the other 15 degrees more, this would help us to see if we go above this temperature (glass transition temperature), will fetch us a better results or make our resin production faster. Considering this, the levels were: (a) 80°C, 120°C, 140°C (b) 87.5°C, 127.5°C, 147.5°C and (c) 95°C, 135°C, 155°C
- Time: This process is very time consuming so we tried to reduce it. Instead of having 3 hours for each phase we tried with one and two hours less, so we had 3+3+3, 2+2+2 and 1+1+1, so we see how this influences the mechanical properties. The less time we consume, the more optimized our process. The levels were (a) 1 hour,1 hour, 1 hour, (b)2 hours, 2 hours, 2 hours and (c)3 hours, 3 hours, 3 hours.
- Flame retardant: To the mixture of resin, we added flame retardant which is a substance that prevents or inhibits the outbreak of fire. We used the following proportions: 0%, 30% and 50%. This proportions were above the

resin we had, not the whole mixture. The goal was to have the greatest proportion of flame retardant without affecting the maximum stress the resin can support. The levels are 0% of flame retardant, 30% of flame retardant and 50% of flame retardant.

After defining the factors and levels, we had 9 factors and 9 levels, which resulted in 27 combinations and therefore 27 experiments. As it would be time consuming and very costly, we applied the Taguchi matrix, which resulted 9 experiments that could guess the best combination of the factors to our purpose. The Taguchi matrix with statistics professional programs (Minitab) was explored. Introducing the data, it was easy to generate the combination below.

	Time phase	Temp ini	Flame retardant
1	1	80,0	0
2	1	87,5	30
3	1	95,0	50
4	2	80,0	30
5	2	87,5	50
6	2	95,0	0
7	3	80,0	50
8	3	87,5	0
9	3	95,0	30

Figure 2. Experiments conducted generated by the matrix.

Under laboratory conditions, the experimental campaign was carried out with a universal material testing equipment. The loading point was moved at a constant displacement rate of 2 mm/min during the 3-point bending tests. The machine's load cell had a capacity of 2kN. A wire saw machine was used to create the crack in the resin samples, and precracking was also done to sharpen the crack's tip. Figure 4 displays the sample dimensions that are assumed. To obtain a realistic number, the actual dimensions of the incision were measured from the broken specimen in accordance with the standard's instructions.

One of the key characteristics determined by the fracture toughness tests is the material's resistance to fracture and crack propagation. Fatigue pressures, material discontinuities, or manufacturing flaws could all contribute to the crack. It is not always possible to prevent defects from arising during manufacture, therefore it is important to take the fatigue lifetime into account. Numerous crucial details on the mechanism of breaking, such as the type of stresses and the direction of the crack's propagation, may be found by analysing the fracture surface. Figure 5 displays the specimen's breakthrough surface without any additions.

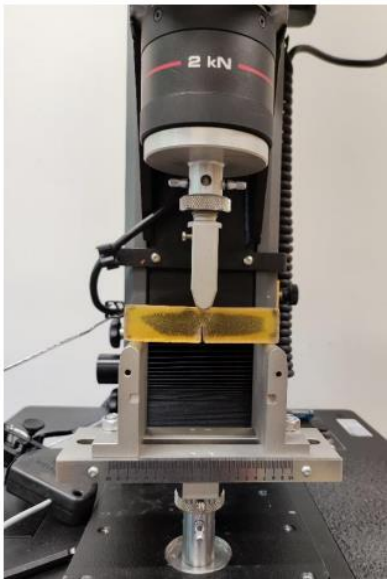


Figure 3. 3-points bending experimental setup.

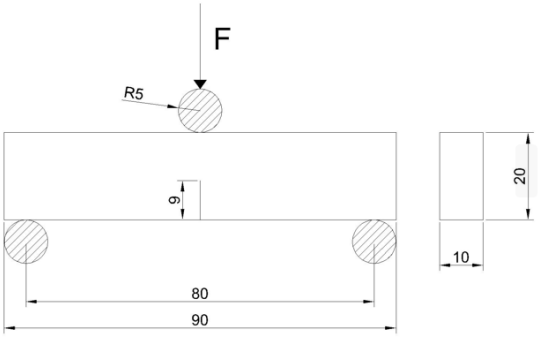


Figure 4. Dimensions of the performed experiment

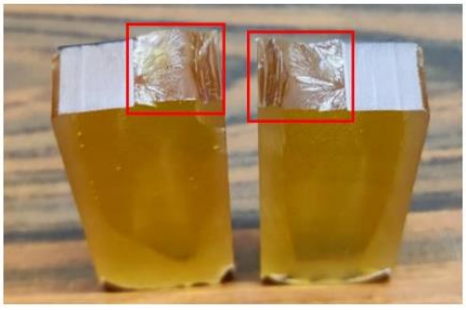


Figure 5. Crack length (sample without flame retardant)

In order to better present the results, a marking system was introduced to facilitate sample identification. Each of the samples has been marked according to the following pattern:

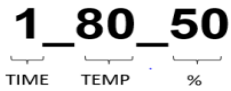


Figure 6. The code of the marked resin specimens

In the case presented on Figure 6 the applied parameters are:

- 1-hour phases,
- 80 degrees of starting temperature
- 50 percentage of the flame retardant

The visualisation of the applied heating cure is on the Figure 7. The slope of the graph is dictated by the need to maintain the maximum heating rate in order to reduce the formation of heat cracks.

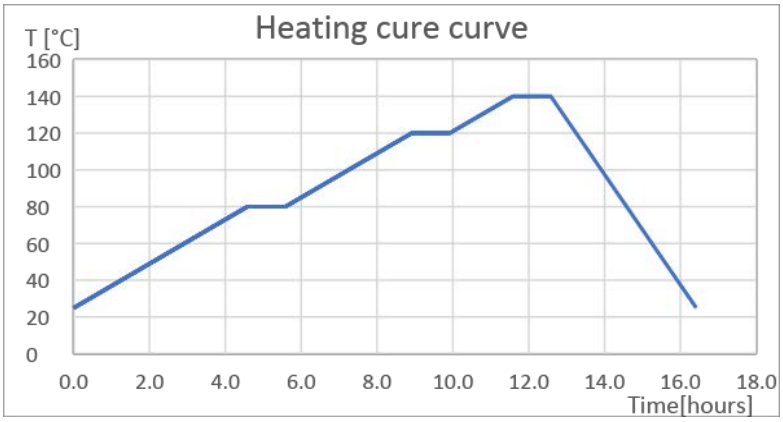


Figure 7. Sample chart of the heating cure curve

3. RESULTS AND DISCUSSION

Figure 8 displays the data collected from the experimental programme. The material's ability to withstand plastic deformation up until fracture was determined by the specimens' mechanical behaviour under load. The stress intensity factor computation and subsequent consideration will make use of linear elastic fracture mechanics. For brittle, homogeneous materials like resin, analysis of the stress intensity factor K allows one to forecast the stress condition close to the notch's tip. Following the test, each specimen was measured in order to determine the sample's

geometrical values. The assessment of fracture toughness was done using the greatest force that the testing apparatus could produce.

Material	Thickness B	Width W	Crack length a	Force [N]	KI
1,80,0 S45	10,1	20	11,3	292	3,123
1,80,0 S41	10,2	20	10,8	468	4,515
1,80,0 S42	10	20	11	358	3,654
2,80,30 S31	10	20	10,5	212	1,978
2,80,30 S32	10	20	12,5	218	3,012
2,80,30 S33	9	20	10,75	264	2,861
3,95,30 S22	8,5	20	11,2	210	2,618
3,95,30 S21	9,4	20	11,6	415	5,055
3,95,30 S23	9,6	20	11,1	385	4,171
1,88,30 S12	10,8	20	11,4	301	3,069
1,88,30 S15	9,9	20	13	300	4,692
1,88,30 S13	10,7	20	10,6	278	2,467
2,95,0 61	9,3	20	8,6	357	2,640
2,95,0 62	11	19,7	7,7	262	1,498
2,95,0 63	10,6	20	8,4	345	2,174
2,88,50 71	9,5	20	7,8	242	1,563
2,88,50 72	9,4	20,4	8,5	188	1,284
2,88,50 73	9,5	20	8,7	201	1,477
1,95,50 81	9,5	20,3	8,4	195	1,317
1,95,50 82	9,5	20,2	9,5	195	1,572
1,95,50 83	9,5	20	7,5	199	1,233
3,88,0 91	10	20	8,6	284	1,953
3,88,0 93	8,8	19,8	8,1	495	3,697
3,88,0 94	10	20	8,6	288	1,981
3,80,50 101	8,6	20	11,1	213	2,576
3,80,50 103	9,5	20	11,6	411	4,954
3,80,50 105	9,4	20	11,2	399	4,498

Figure 8. Experimental results

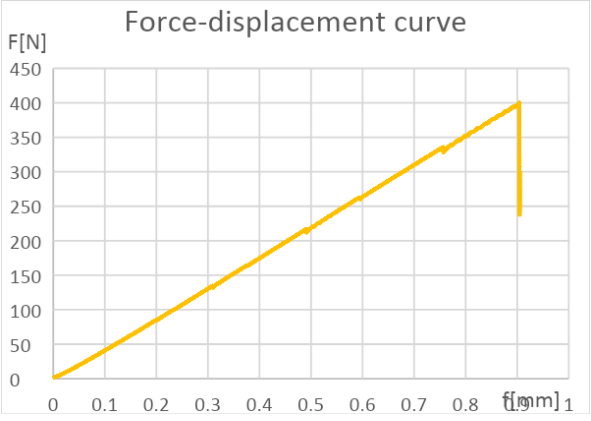


Figure 9. Force-displacement curve of the 3-point bending resin test

The mechanical behaviour of the specimens in the stress state and the response of the testing machine for the applied displacement rate of the loading point are presented on Figure 9.

The stress intensity factor K_I in the loading Mode-I is calculated based on the following equation[23-25]:

$$K_I = \sigma_0 F_I \sqrt{\pi a}$$

$$\sigma_0 = \frac{3PL}{2W^2 B}$$

The obtained average values of the resin fracture toughness are presented on Figure 10.

Material	KI
1,80,0	3,764
1,88,30	3,409
1,95,50	1,374
2,80,30	2,617
2,88,50	1,441
2,95,0	2,104
3,80,50	4,009
3,88,0	2,544
3,95,30	3,948

Figure 10. Average experimental results

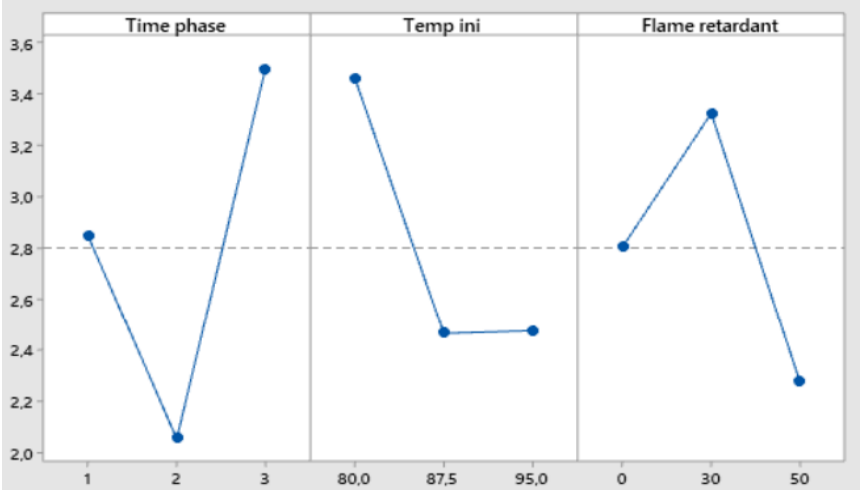


Figure 11. Effects of the parameters on K_I

The experimental campaign's outcomes were utilised to analyse how each element affected the stress intensity factor KI. The ensuing visuals display the

outcomes. The mean value for the whole set of data is shown by the dashed line.

- Time of each phase

From the perspective of the manufacturer, process time is an important consideration. A decrease in time results in a decrease in the company's expenses. The goal is to choose the solution that best fits the needs of the product. The one- or three-hour time cure in this instance should be taken into account. The producer's suggested time represents the factor's optimal value. Reducing the phase's duration may be beneficial if the fracture toughness is at the safety level.

- Temperature

The fracture toughness characteristic decreases when the process temperature rises. Increased temperatures result in energy waste and needless expenses. The value that the datasheet recommends is the best choice.

- Flame retardant

The resin microstructure is affected differently by the addition of flame retardants, such as aluminium trihydroxide, depending on the additive's concentration, particle shape, and surface preparation. According to the data, 30% of the particles are the optimum option for the resin's characteristics.

The conducted research allows to verify the parameters recommended from the resin manufacturer and the influence of the various factors on the mechanical properties such as fracture toughness. The best results were obtained from the temperature sequences 80°C, 120°C, 140°C, 3 hours of the temperature standstill and 30 percent of the flame retardant.

4. CONCLUSIONS

The primary goal of designing experiment methods, such the Taguchi method, is to optimise the parameters of the product through the utilisation of multiple components in the trials. These methods help cut down on the quantity of experiments conducted and conserve time, energy, and money. This approach's primary drawback is how mistakes affect the way the experiments turn out. More accuracy and preservation of condition should be used in the investigation. Errors made during a campaign have a greater influence on the outcome and are more difficult to identify.

REFERENCES

[1] Mouritz AP. *Introduction to aerospace materials*. Elsevier; 2012.

[2] Sojka SA, Moniz WB. *The curing of an epoxy resin as followed by carbon-13 NMR spectroscopy*. J Appl Polym Sci 1976;20:1977–82.

[3] Cañavate J, Colom X, Pages P, Carrasco F. *Study of the curing process of an epoxy resin by FTIR spectroscopy*. Polym Plast Technol Eng 2000;39:937–43.
[4] González MG, Cabanelas JC, Baselga J. *Applications of FTIR on epoxy resins-identification, monitoring the curing process, phase separation and water uptake*. Infrared Spectroscopy-Materials Science, Engineering and Technology 2012;2:261–84.
[5] Massingill Jr JL, Pabon Jr RA. *Modified advanced epoxy resins* 1989.
[6] May C. *Epoxy resins: chemistry and technology*. Routledge; 2018.
[7] Wu F, Zhou X, Yu X. *Reaction mechanism, cure behavior and properties of a multifunctional epoxy resin, TGDDM, with latent curing agent dicyandiamide*. RSC Adv 2018;8:8248–58.
[8] Erdmann M, Trappe V, Sturm H, Braun U, Duemichen E. *Cure conversion of structural epoxies by cure state analysis and in situ cure kinetics using nondestructive NIR spectroscopy*. Thermochim Acta 2017;650:8–17.
[9] Mphahlele K, Ray SS, Kolesnikov A. *Cure kinetics, morphology development, and rheology of a high-performance carbon-fiber-reinforced epoxy composite*. Compos B Eng 2019;176:107300.
[10] Rogers MG. *The structure of epoxy resins using NMR and GPC techniques*. J Appl Polym Sci 1972;16:1953–8.
[11] Merad L, Cochez M, Margueron S, Jauchem F, Ferriol M, Benyoucef B, et al. *In-situ monitoring of the curing of epoxy resins by Raman spectroscopy*. Polym Test 2009;28:42–5.
[12] Wang LW, Fernando GF. *Cure monitoring of epoxy resin by simultaneous DSC/FTIR*. Adv Mat Res 2014;881:905–8.
[13] Uttarwar PB, Raini SK, Malwad DS. *Optimization of process parameter on Surface Roughness (Ra) and Wall Thickness on SPIF using Taguchi method*. International Research Journal of Engineering and Technology 2015;2:781–4.
[14] Naiju CD, Anil PM. *Influence of operating parameters on the reciprocating sliding wear of direct metal deposition (DMD) components using Taguchi method*. Procedia Eng 2017;174:1016–27.
[15] Lee BH, Abdullah J, Khan ZA. *Optimization of rapid prototyping parameters for production of flexible ABS object*. J Mater Process Technol 2005;169:54–61.
[16] Uddin MS, Sidek MFR, Faizal MA, *Ghomashchi R, Pramanik A. Evaluating mechanical properties and failure mechanisms of fused deposition modeling acrylonitrile butadiene styrene parts*. J Manuf Sci Eng 2017;139:081018.
[17] Hamza I, Abdellah EG, Mohamed O. *Experimental optimization of fused deposition modeling process parameters: a Taguchi process approach for dimension and tolerance control*. Proceedings of the international conference on industrial engineering and operations management, 2018, p. 2992–3.
[18] Ahmad MN, Ab Rahman MH, Maidin NA, Osman MH, Wahid MK, Mohamed Saiful Firdaus H, et al. *Optimization on Surface Roughness of Fused Deposition Modelling (FDM) 3D printed parts using taguchi approach. Intelligent Manufacturing and Mechatronics: Proceedings of the 2nd Symposium on Intelligent Manufacturing and Mechatronics–SympoSIMM 2019, 8 July 2019, Melaka, Malaysia*, Springer; 2020, p. 230–43.
[19] Ahmad MN, Ab Rahman MH, Maidin NA, Osman MH, Wahid MK, Mohamed Saiful Firdaus H, et al. *Optimization on Surface Roughness of Fused Deposition Modelling (FDM) 3D printed parts using taguchi approach. Intelligent Manufacturing and Mechatronics: Proceedings of the 2nd Symposium on Intelligent Manufacturing and Mechatronics–SympoSIMM 2019, 8 July 2019, Melaka, Malaysia*, Springer; 2020, p. 230–43.
[20] Qattawi A. *Investigating the effect of fused deposition modeling processing parameters using Taguchi design of experiment method*. J Manuf Process 2018;36:164–74.
[21] Onwubolu GC, Rayegani F. *Characterization and optimization of mechanical properties of ABS parts manufactured by the fused deposition modelling process*. International Journal of Manufacturing Engineering 2014;2014:1–13.

[22] Uddin MS, Sidek MFR, Faizal MA, Ghomashchi R, Pramanik A. *Evaluating mechanical properties and failure mechanisms of fused deposition modeling acrylonitrile butadiene styrene parts*. J Manuf Sci Eng 2017;139:081018.
[23] Fett, T.; Gerteisen, G.; Hahnenberger, S.; Martin, G.; Munz, D. *Fracture tests for ceramics under mode-I, mode-II and mixed-mode loading*. J. Eur. Ceram. Soc. 1995, 15, 307–312.
[24] Fett, T. *Stress intensity factors for edge crack subjected to mixed mode four-point bending*. Theor. Appl. Fract. Mech. 1991, 15, 99–104.
[25] Araki, W.; Nemoto, K.; Adachi, T.; Yamaji, A. *Fracture toughness for mixed mode I/II of epoxy resin*. Acta Mater. 2005, 53, 869–875.

Corresponding author:
grzegorz.lesiuk@pwr.edu.pl

DOI: 10.37190/JoT2023_06

Bc. Tomáš BELLAY and Martin LAŠ*

RESILIENCE AND IMPROVEMENT STRATEGIES FOR CRITICAL INFRASTRUCTURE IN PARDUBICE

Keywords: *Pardubice, Resilience and improvement strategies, Pardubice Region*

The work focuses on the question of resilience and improvements strategies for critical infrastructure in Pardubice.

INTRODUCTION

This thesis focuses on the critical infrastructure of the City of Pardubice in the context of the Pardubice Region. The thesis describes selected subsystems of the critical infrastructure. The authors also offer possible solutions for each of the problems.

The authors study at the University of Pardubice, therefore they chose this topic. This topic was chosen by the authors for the Blended Intensive Programme (BIP) in Zagreb, which is part of Erasmus+.

1. BASIC INFORMATION

Pardubice is a middle-sized city east of Prague. It is the capital city of the Pardubice Region, with over 90,000 citizens. Pardubice is a university city with more than 10,000 students. The town is situated on the railway corridor line from Prague to Česká Třebová. [1]

1.1. PARDUBICE REGION

In the Pardubice region, more than 550,000 people live. It is situated in the east of Bohemia and covers an area of 4,500 km^2, surrounded by the Hradec Králové

* Univerzita Pardubice, Dopravní fakulta Jana Pernera

Region, Central Bohemia Region, Vysočina Region, South Moravia Region, and Olomouc Region. The region also shares a part of its border with Poland.

The administrative centre is located eccentrically in the western part of the region. In the eastern part of the region, there are regional towns with a population of between 10,000 and 30,000 residents. [1]

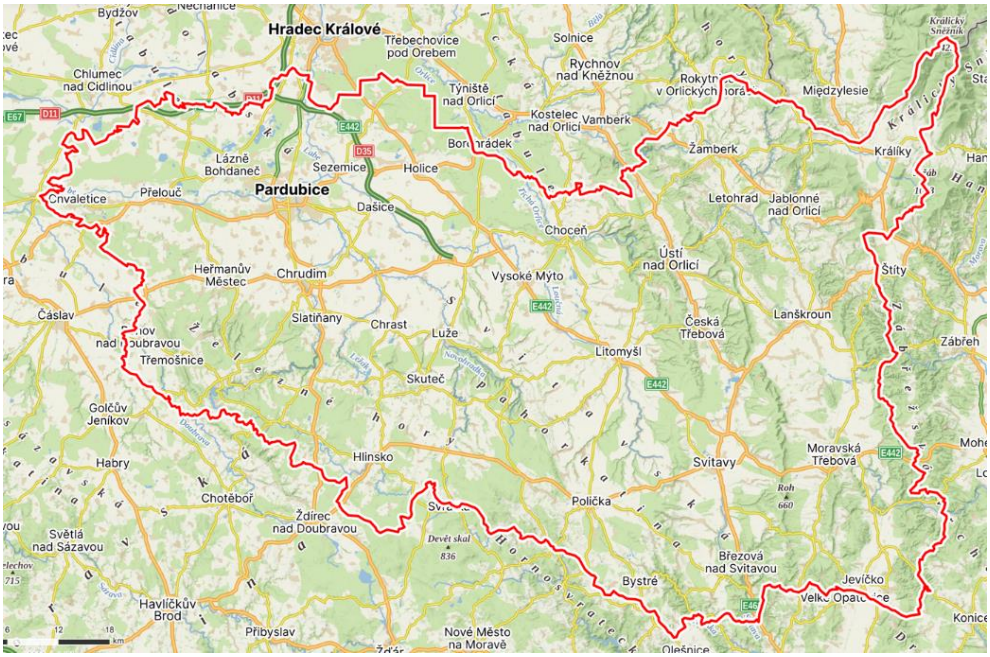


Fig. 1. Map of Pardubice Region [2]

1.1.1. ROAD TRAFFIC

Pardubice Region is suffering from the low density of highway. There is the D11 motorway Prague – Hradec Králové which partly passes through this region. This highway is connected to the D35 highway which provides connectivity to the region.

This motorway is planned to be extended to Olomouc. More than 60 kilometers are planned to be built, or they are already under construction. This extension will increase the accessibility of the geographical centre of the region. Currently, the connection between the central and eastern parts of the region is provided by the I/35 road, which, however, has insufficient capacity. This is mostly caused by passages leading through towns.

Another major road is the I/35, connecting Hradec Králové, Pardubice, Chrudim, and the whole region to the D1 highway. [3]

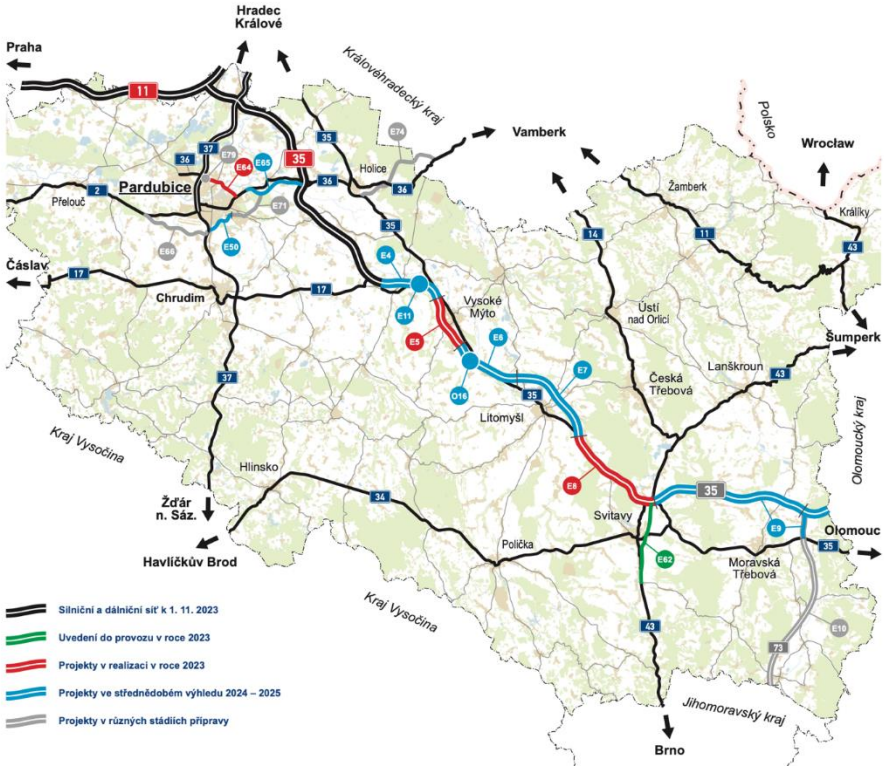


Fig. 2. Map of highway network in Pardubice [3]

Fig. 3. Pardubice junction after the reconstruction [4]

1.1.2. RAILWAY TRAFFIC

Railway infrastructure is more important for the Pardubice Region. The largest towns in the Pardubice Region (Pardubice, Přelouč, Choceň, Ústí nad Orlící, Svitavy) are connected to the railway 001, 010 corridor (1st Czech transit corridor).

This means that, for example, between Prague and Pardubice, you can take a train every 10 minutes during peak times and normally once an hour throughout the day.

Another important railway line is railway number 030, which connects Pardubice with Hradec Králové. This line is experiencing a high increase in the number of passengers thanks to modernization and the deployment of new trains.

Railway number 238 to Chrudim is also a relatively important link. Other lines serve as peripheral connections and are relatively lightly used. This is mainly due to uncompetitive commuting times. [4]

1.1.3. CRITICAL INFRASTRUCTURE

The most important are the power plant located in Chvaletice and the power plant for hot water in Opatovice nad Labem. These two power plants supply electricity for the Pardubice Region and the Hradec Králové Region.

Another example of critical infrastructure in the Pardubice Region is Pardubice Hospital. It is the largest hospital in the region. It is necessary to protect the hospital against any cyber-attacks. [1]

1.2. THE CITY OF PARDUBICE

The historic centre of Pardubice was built on the left bank of the Labe River near the confluence with the Chrudimka River. Originally, the town developed only on the left bank of the river. However, with the advent of industrialization in the 19th century, Pardubice experienced a high population growth. The right bank of the Labe River, which was not very industrially developed until then, became a natural place for the city to expand.

At that time, only one bridge connected the two banks. In the middle of the 20th century, massive construction caused a great densification of the built-up area. This trend was mainly due to the new prefabricated flats that were built on the periphery of the city.

The growth of the built-up area also meant the absorption of the surrounding villages, which were subsequently properly integrated into the perimeter of the city. Due to the not always natural integration of the surrounding villages within one administrative unit, the built-up area of Pardubice is not very compact. The built-up area is often separated by narrow corridors of green spaces that follow the original boundaries of natural settlements. [5]

1.2.1. ROAD TRAFFIC

Public urban transport in Pardubice is operated by the company "Dopravní podnik města Pardubice". It's owned by the city. The company operates bus and trolleybus transport in the city, with 74 buses and 56 trolleybuses. [6]

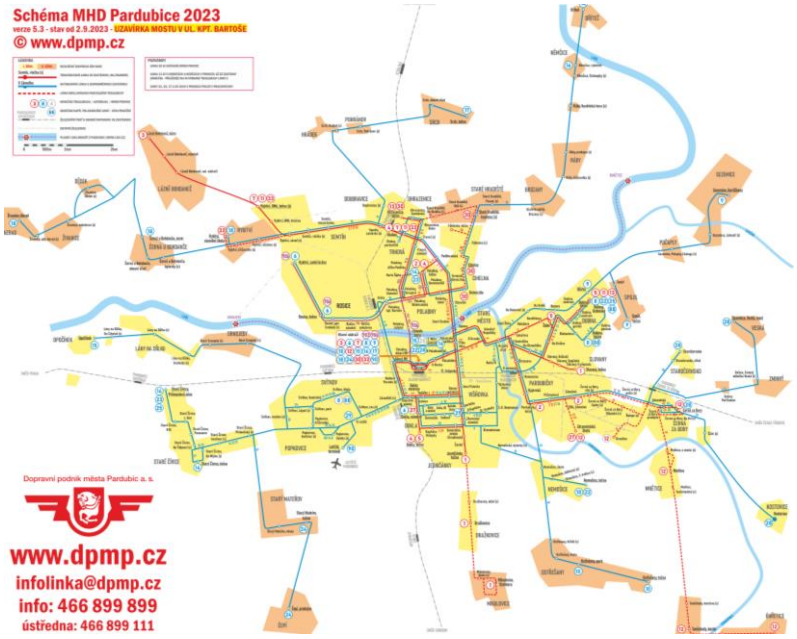


Fig. 4. Scheme of Pardubice urban public transport [7]

The A36 road runs through Pardubice. This road connects Pardubice with Sezemice and Borohrádek. It's highly used by lorries and cars. As Pardubice does not have a functional bypass, traffic jams often occur in the centre of the city. [3]

1.3. CRITICAL INFRASTRUCTURE

As was mentioned previously, one of the most critical infrastructures in Pardubice is the hospital. The hospital is located in the southern part of Pardubice. Hospitals are one of the key institutions in our society. [5]

Another example could be the bridges in Pardubice. Although the Labe River flows through Pardubice, there are only three bridges, one of which is in a state of disrepair.

In the next chapter, the authors would like to introduce each of the critical infrastructures and describe them. [3]

2. BRIDGES IN PARDUBICE

A significant part of the population lives in the area north of the Labe River. For these inhabitants, there was a need to ensure adequate connections with the rest of the city, so the river has been spanned by several bridges over the years.

2.1. PAVEL WONKA BRIDGE

The Pavla Wonka Bridge (in picture 5 - yellow) is located in the central part of the city, connecting Masaryk Square - one of the transport hubs for public transport - with Polabiny or Stavařov, a residential area. The bridge is primarily used for road traffic, as it carries the road II/324. The trolleybus line runs above the roadway in each direction. Additionally, there is a mixed pedestrian and cycling path on both sides of the road. Until the construction of the bridge on the A37 road in the western part of the city, this bridge was the only capacity link for transit car traffic. [3]

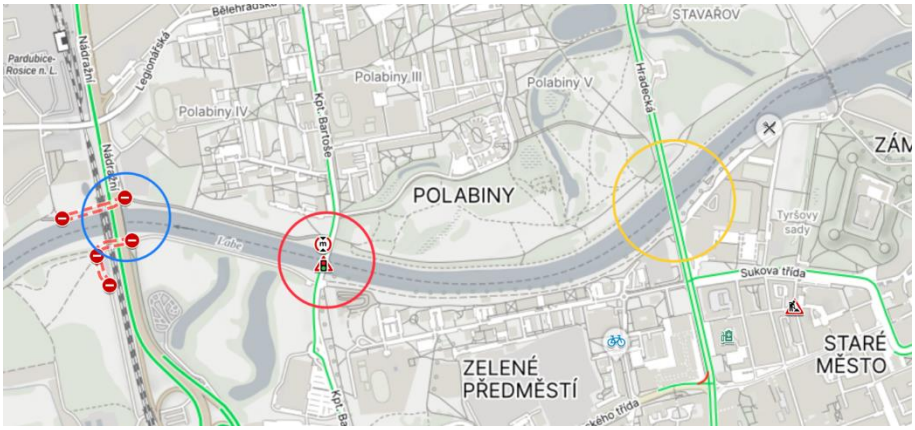


Fig. 5. Map of Pardubice‘s bridges [8]

The protection of the bridge from physical influences was already addressed during construction. In addition to the river itself, the bridge crosses an inundation area, thus ensuring protection not only against periodic flooding but also against flooding from thawing and intense rainfall. According to the flood plan of the city of Pardubice, the bridge should be secured against 100-year water. The technical condition of the bridge is also monitored. The bridge deck consists of a field of prestressed concrete. This type of structure is susceptible to degradation, mainly due to possible corrosion of the steel cables. Hence, a visual inspection of the steel cables is periodically conducted. Non-invasive methods, such as resonance scanning, are also used for inspecting the bridge. The bridge underwent repairs in 1965, 1983, 1987, 2003, 2006, and 2022. [9] [10]

2.2. BRIDGE OF THE I/37 ROAD

The Nádražní Street Bridge (in the picture 5 – blue) is the highest capacity road link. It is located on the I/37 road, which leads from Trutnov through Pardubice to Velké Bíteš, where it is used as a feeder to the D1 motorway. The bridge consists of

two separate bridge decks with 2+2 lanes, which are connected to a part of the road classified as a motor vehicle road. In 2022, trolley poles were installed on the bridge deck, which increased the robustness of the public transport system.

Given the relatively low age of the bridge and the recent reconstruction that took place in 2017, the bridge is in reasonably good condition. The bridge is routed completely outside the flood plain. Monitoring of the condition of the structure is carried out periodically. [11]

2.3. KAPITÁN BARTOŠ BRIDGE

The Kapitán Bartoš Bridge (in the picture 5 – red) connects the eastern part of Polabiny with the Green Suburb. The bridge is of regional importance. Currently, due to its poor condition, vehicle passage is restricted. The trolleybus track that runs over the bridge is presently unused because of the excessive weight of trolleybuses. A proposal for constructing a new bridge is currently being discussed.

Fig. 6. New look of Kapitán Bartoš bridge [12]

2.4. RAILWAY BRIDGE OF TRACK 031

The railway bridge over the Labe lies on the line 031, which connects Hradec Králové with Pardubice. This line is one of the busiest in the region. At present, the

original bridge deck has been removed and replaced by a completely new construction. [4]

2.5. POTENTIAL SOLUTIONS

The construction of the north-eastern bypass of Pardubice will contribute significantly to reducing the vulnerability of the road network. This bypass will reduce the intensity of transit traffic in the west-east direction, which currently leads through the city's inner ring road. In emergency situations it can also serve as an alternative connection. Construction began in December 2022. Completion is scheduled for 2025.

3. PARDUBICE'S HOSPITAL

Hospitals are a very important part of the Czech Republic. The Czech Republic has more than 150 hospitals. It's necessary to keep all of them safe.

3.1. CYBERSECURITY

In 2019, Russian hackers attacked one of the regional hospitals in the Czech Republic using ransomware. The Hospital in Benešov was paralyzed for more than 20 days. The attack caused damages exceeding 59 million CZK. The hospital lost some data, and its software was also damaged.

It was one of the biggest attacks in the history of the Czech Republic. After that, all the state-owned hospitals renew their server security systems to be safer. [13]

3.2. COVERAGE OF THE AREA BY THE RESCUE CORPS

The key thing is to be on the scene of the emergency in time. In the picture, you can see the rescue service base (Hradec Králové, Jihlava, Olomouc, Brno). Air emergency services are not provided in Pardubice. Therefore, this service is outsourced by other regions.

Another problem is the availability of emergency services via road in Pardubice. The hospital is located beyond the railway track. There is only one bridge that crosses the railway, which is potentially problematic for the availability of emergency services. In 2022, this bridge was under construction, and it was difficult for emergency services to reach the location on time. [14]

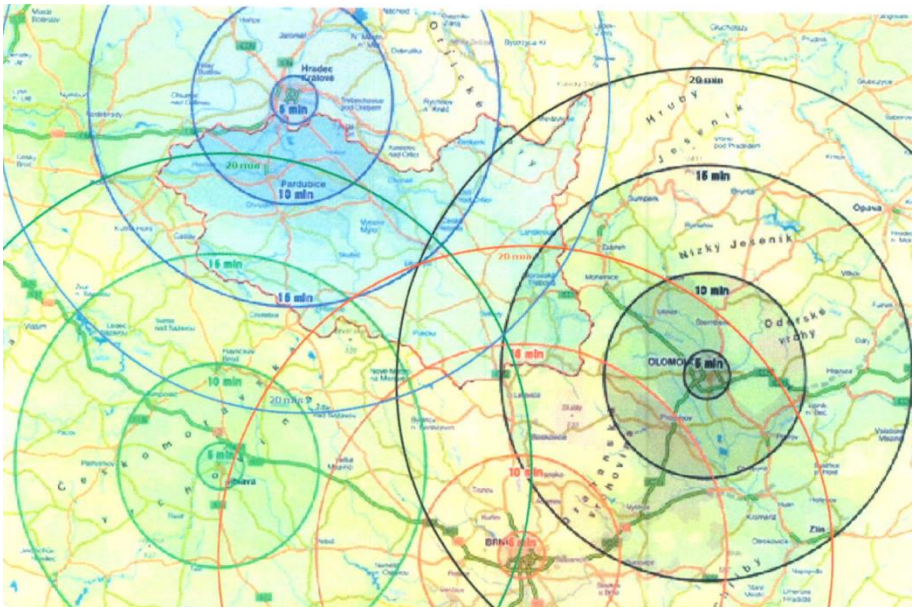


Fig. 7. Availability of emergency services in the Pardubice Region [14]

3.3. POTENTIAL SOLUTIONS

There are few things to change to keep the hospital safe and to keep citizens safe as well.

- Keep protect from hackers,
- relocate the rescue service base.

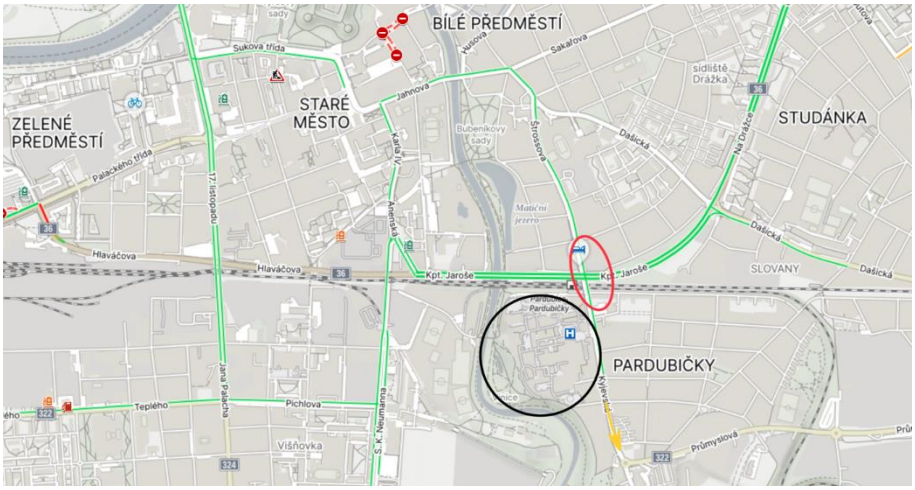


Fig. 8. Map of location of Pardubice's hospital [8]

The first thing is already being done. Pardubice's hospital has its own IT team for keeping software updated and safe. The second thing is much more complicated. As you can see in picture 6, the hospital is shown in a black circle. The problematic bridge is shown in red. It is a problem to choose another route other than this one (via the bridge). The only possible way is to take a longer route to the south (yellow arrow).

4. Power Plant

Every city needs electricity. For Pardubice, Chvaletice's power plant has been operating for over 40 years. Today, it is normal for the transmission system to be interconnected, but in the past, Chvaletice was the main power plant for part of the Middle Bohemia Region and Pardubice Region. The other power plant is located between Pardubice and Hradec Králové and is called Opatovice. [15]

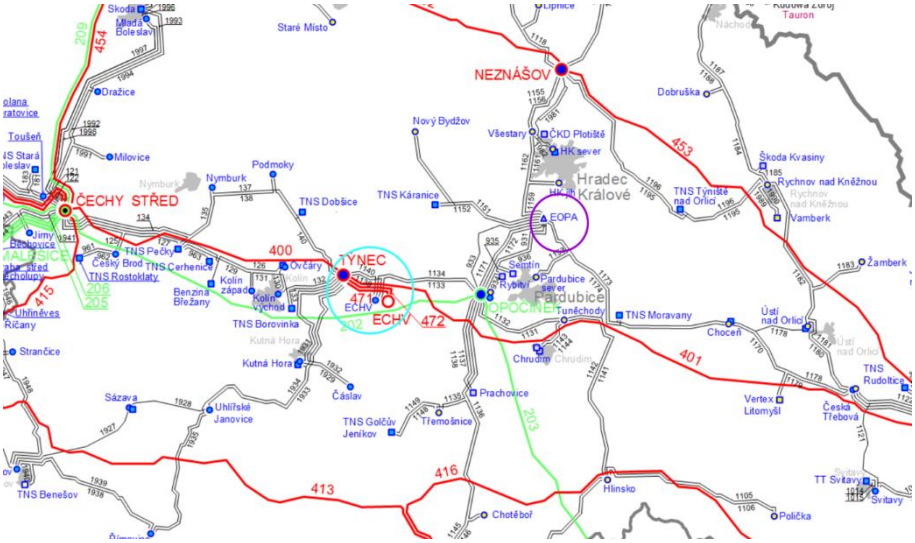


Fig. 9. Scheme of transmission system [16]

4.1. OPATOVICE NAD LABEM

What is still very important for Pardubice and Hradec Králové? The power plant in Opatovice nad Labem produces electricity and hot water for both towns, as well as Chrudim, Lázně Bohdaneč, and other smaller cities nearby. The total length of the pipes is 319 kilometers.

The power plant burns coal, which is not environmentally friendly. Another problem is that if there are any issues with coal logistics, more than 300,000 people will be left without hot water.[17]

4.2. CHVALETICE

Chvaletice's power plant is not producing hot water; instead, it is much more powerful (820 MW). It is owned by the private company Seven Energy. Like Opatovice's power plant, it burns coal to produce electricity. This power plant compensates for fluctuations in the grid and serves as a potential backup. [15]

4.3. POTENTIAL SOLUTION

The best option would be to develop a new sustainable power plant for supplying energy and hot water. It is also important to protect these two power plants as without them, the region will be without electricity and hot water.

REFERENCES

[1] *Pardubický kraj*. Online. C2023. Dostupné z: https://www.pardubickykraj.cz. [cit. 2023-12-04].
[2] *Pardubický kraj*. Online. Mapy.cz. C2023. Dostupné z: https://mapy.cz/zakladni?l=0&source=regi&id=7&ds=1&x=16.1151034&y=49.9111144&z=9. [cit. 2023-12-04].
[3] *Síť – Pardubický kraj*. Online. Ředitelství silnic a dálnic. 2023. Dostupné z: https://kraje.rsd.cz/MAPY/vystavba-kraje/rsd-mapa-vystavba-kraj-e.pdf. [cit. 2023-12-04].
[4] *Interaktivní mapa Správy železnic*. Online. Správa železnic. C2023. Dostupné z: https://mapy.spravazeleznic.cz. [cit. 2023-12-04].
[5] *Město Pardubice – turista*. Online. Město Pardubice. 2023. Dostupné z: https://pardubice.eu/turista. [cit. 2023-12-04].
[6] Výroční zpráva Dopravního podniku města Pardubic. Online. Dopravní podnik města Pardubic. Roč. 2022, č. 1, s. 67. Dostupné z: https://www.dpmp.cz/download/annual_report_cs/1686073634_cs_vyrocni-zprava-2022-dpmp.pdf. [cit. 2023-12-04].
[7] *Schéma sítě MHD*. Online. Dopravní podnik města Pardubic. C2023. Dostupné z: https://www.dpmp.cz/cestovani-mhd/schema-site-mhd-pardubice.html. [cit. 2023-12-04].
[8] *Mapy.cz*. Online. C2023. Dostupné z: https://mapy.cz/zakladni?x=15.6252330&y=49.8022514&z=8. [cit. 2023-12-04].
[9] *Rekontrukce mostu Pavla Wonky*. Online. In: Pardubice. S. 19. Dostupné z: https://www.ebeton.cz/wp-content/uploads/2007-3-12_0.pdf. [cit. 2023-12-04].
[10] *Oprava Wonkova mostu v centru Pardubic se přesouvá na léto*. Online. In: Pardubický deník. C2023. Dostupné z: https://pardubicky.denik.cz/zpravy_region/oprava-wonkova-mostu-v-centru-pardubic-se-posouva-na-leto-potrva-11-mesicu-20221.html. [cit. 2023-12-04].
[11] *Trolejbusy budou muset jezdit přes Paramo: troleje tam ale ještě nejsou*. Online. In: ITI Hradecko-pardubické alglomerace. C2023. Dostupné z: https://iti.hradec.pardubice.eu/ ?site=trolejbusy-budou-muset-jezdit-pres-paramo,-troleje-tam-ale-jeste-nemaji. [cit. 2023-12-04].
[12] *Širší a s oddělenými pruhy pro cyklisty. Pardubičtí zastupitelé rozhodli o nové podobě mostu kpt. Bartoše*. Online. In: Zdopravy.cz. C2023. Dostupné z: https://zdopravy.cz/sirsi-a-s-oddelenymi-

pruhy-pro-cyklisty-pardubicti-zastupitele-rozhodli-o-nove-podobe-mostu-kpt-bartose-186261/. [cit. 2023-12-04].
[13] *Kyberútok na nemocnici v Benešově způsobil škodu přes 59 milionů. Pachatele se vypátrat nepodařilo*. Online. In: Rozhlas.cz. C2023. Dostupné z: https://www.irozhlas.cz/zpravy-domov/kyberutok-kyberneticky-utok-nemocnice-v-benesove-skoda-pachatel-hacker_2008180912_ako. [cit. 2023-12-04].
[14] *Plán pokrytí Pardubického kraje výjezdovými základnami*. Online. In: Pardubice. S. 6. Dostupné z: https://www.luze.cz/e_download.php?file=data/editor/129cs_1.pdf&original=Plan_pokryti_Pardubickeho_kraje_vyjezdovymi_zaklad.pdf. [cit. 2023-12-04].
[15] *Chvaletická elektrárna*. Online. Seven Energy. C2023. Dostupné z: https://www.7.cz/cz/skupina/seven-ec.html. [cit. 2023-12-04].
[16] *Elektrizační soustava ČR*. Online. OTE ČR. C2023. Dostupné z: https://www.ote-cr.cz/cs/statistika/elektrizacni-soustava-cr.png. [cit. 2023-12-04].
[17] *Elektrárny Opatovice*. Online. C2023. Dostupné z: https://www.eop.cz. [cit. 2023-12-04].

Corresponding author:
Tomáš Bellay, st62323@upce.cz

racowników oprócz korzyści wynikających z oszczędności dla linii
tniczych, dzięki obniżeniu niezbędnej liczby pracowników oraz niższym
sztom operacyjnym, pasażerowie będą również korzystać z nowych
chnologii na lotnisku skrócenie czasu oczekiwania w kolejkach i
ożliwość sprawdzenia dostępnych na lotnisku udogodnień w kioskach
moobsługowych to tylko kilka z licznych nowości, jakie będzie miał do
oferowania terminal przed oddaniem go do użytku odbędą się
tensywne testy zintegrowanych systemów lotniskowych tak, aby
nieczne procedury od samego początku użytkowania były w pełni
rawne i satysfakcjonowały pasażerów, którzy bardzo cenią
rminal natomiast będzie gotowy w 2020 roku zostanie zbudowany na
080 hektarach gruntu changi airport posiadając 5 terminali będzie w
anie obsłużyć ponad 135 milionów osób w każdym roku planowana jest
wnież poprawa infrastruktury drogowej, aby zapewnić wygodny dostęp
terminali oczekujących na lot w holu lotniska changi znajduje się green
all, czyli ściana bujnej, egzotycznej roślinności, która ma 300 m szerokości
jest wysoka na kilka pięter wysokości na lotnisku znajduje się też
otylarnia, czyli dwupiętrowy ogród z wodospadem i ponad tysiącem
otyli różnych gatunków pasażerowie mają do dyspozycji ogrody:
ktusowy, słonecznikowy, orchidei czy też ogród paproci a zmęczeni
odróżą mogą też odwiedzić specjalne sypialnie, centrum spa i baseny.
iłośnicy gier mają szansę skorzystać ze strefy , gdzie filmy i gry wideo są
ezentowane w trzech wymiarach dodatkową atrakcją dla pasażerów jest
ielka zjeżdżalnia wysokości zainstalowane przyrządy ils do obsługi
ezpiecznego lądowania samolotów w każdych warunkach pogodowych.
owocześniejsze i wieksze rosły również wymagania wobec ich miejsc
ostojo tniska,
oskon nym, z
rofes yjnym.
ajważ lotów.
ontrol wanie,
ontrol i zaraz
ed lądowaniem a także kołowaniu tych samolotów i pojazdów na

WUST Publishing House prints can be obtained via mailorder:
zamawianie.ksiazek@pwr.edu.pl
www.ksiegarnia.pwr.edu.pl

ISSN 2450-5870