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FACULTY OF MECHANICAL ENGINEERING
Department of Transport Engineering and Logistics

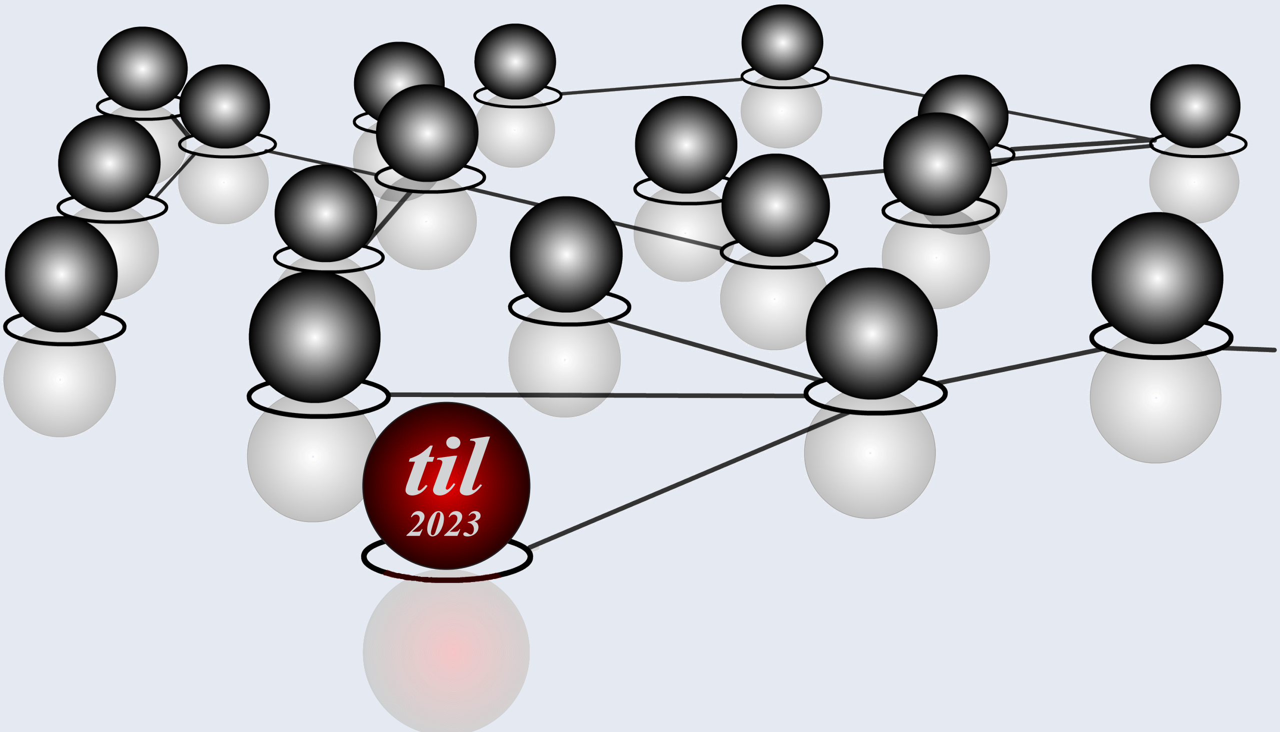
9th INTERNATIONAL CONFERENCE

TRANSPORT & LOGISTICS

warehousing GIS resource GPS goods project management reliability system management GSM efficient AHP production method trafic supply order folw

vehicle routing material flow storage inventory control availability functions structural analysis production logistics control simulation cranes optimisation SCM transportation warehousing maintenance shipping mobile machines city logistics vehicle material handling transport machines management information flow traffic safety controll ergonomy and industrial design design organization supply chain VRP E-business distribution lean operation research reverse logistics

PROCEEDINGS



Niš, Serbia 1 December 2023

THE NINTH INTERNATIONAL CONFERENCE

TRANSPORT AND LOGISTICS

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CONTENTS

FOREWORD

In the field of transport, traffic and logistics, technical systems are created on the basis of strictly rational requirements but completely free forms of solutions and application of the latest technologies. This has led to more efficient systems, better adapted to processes, which in turn has given greater financial sustainability.

The intense global mobility of people, goods and information, with the expected tendency of further growth, indicates the need for education, research and development in the field of transport, traffic and logistics. Evaluating the importance of the development of transport and logistics in the Republic of Serbia and Southeast Europe, in 2002 the European Union, through the TEMPUS programme, adopted and allowed the funding of a three-year project entitled: *The Introduction and Development of a New Study Profile of Transport Flows and Logistics*, which was successfully implemented at the Department of Transport Engineering and Logistics of the Faculty of Mechanical Engineering, University of Niš.

With the aim of presenting the research results and plans in the field of transport and logistics, the Department of Transport Engineering and Logistics of the Faculty of Mechanical Engineering, University of Niš, has thus far organized seven scientific events under the title of Transport and Logistics. The first event was held in 2004, as a symposium, within the TEMPUS project.

The ninth international scientific conference Transport and Logistics – TIL 2023 is being held at the Faculty of Mechanical Engineering in Niš with the old aim but a new and wider scope of the field of transport and logistics, compared with the previous events. The conference is characterized by the participation of a great number of researchers from universities, faculties, institutes and various organizations from Germany, Croatia, Hungary, Macedonia, Turkey and Serbia.

Original, review and professional papers contained in the Conference Proceedings encompass the fundamental scientific areas of transport and logistics related to: transport flows, planning and control of logistics systems, design and maintenance of transport machines and vehicles. However, apart from the fundamental areas, the proceedings include, equally and legitimately, a number of papers from the scientific fields whose studies deal with urban mobility, sustainable development, environmental protection and decision-making criteria.

It can be said, as a general conclusion of the Conference, that the intense global mobility of people, goods and information, with the expected tendency of further growth, points to the needs and current trends of future research in the field of transport and logistics.

Asst. Prof. Dr. Vesna Jovanović

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PLENARY

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DEVELOPING THE TOOL FOR ASSESSING RESILIENCE AND SAFETY CLIMATE ASPECTS IN THE TRANSPORT AND MINING COMPANIES

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Abstract

This manuscript is presenting the process of development of the original software application, e.g. the tool, to be used in assessment of the resilience level and the safety climate indicators in the industrial organizations in the transport and mining sector. The initial data that was used to develop the app was collected using the questionnaire in which employees, segmented in five different organizational levels (e.g. transport and mining machines operators, support workers, first line managers, middle level managers and top level managers), were assessing the present state and the importance of each of the investigated safety indicators. Based on this initial database the starting measurement model was developed that was used to develop the application which calculate the resilience levels of the organizations, based on adequate MCDA methods and four resilience corners approach.

Key words: *resilience, safety climate, software application, artificial intelligence*

1 INTRODUCTION

Organizational resilience in industrial processes is a critical aspect of ensuring a company's ability to withstand and recover from disruptions, whether they are related to workplace safety disruptions, natural disasters, supply chain issues, or other unexpected events. Accordingly, organizational resilience can be defined as the ability of an organization to adapt, recover, and thrive in the face of adversity, uncertainty, and change. It encompasses various aspects of an organization, including its processes, people, technology, and culture.

In accordance to the recent literature, there are four key elements of the organizational resilience, which can be considered as the trends of research in respected field. Those are:

- *Supply Chain Resilience*: which is dealing with ensuring of the resilience across the supply chain, as vital element for industrial processes [1].
- *Change Management*: observed as the ability to adapt to changing circumstances and implement changes smoothly in the process [2].
- *Business Continuity Planning*: Developing and maintaining robust business continuity plans ensures that critical processes can continue in the event of disruptions [3].
- *Risk Management*: Effective risk assessment and management are crucial for identifying potential vulnerabilities in industrial processes. [4].

Besdes being able to define the main goals of organizational resilience in the company, which can be considered as the element of organizational strategy, it is mandatory to set the mechanism for assessment, e.g. the measurement, of the present level of achieved organizational resilience. Organizations can use various resilience indices or metrics to measure and assess their resilience. The instrument that can be proposed as adequate for this purpose is the Resilience Index. [5].

There are lots of recent publications dealing with different models of Resilience Indexes [6-8]. Special aspects of such measurement scales development are those which are implementing advanced technologies such as IoT, AI, and data analytics, which can help to predict and mitigate risks in industrial processes.

This manuscript is presenting the research that is conducted in frame of the project: "*Support Systems for Smart, Ergonomic and Sustainable Mining Machinery Workplaces – SmartMiner*" supported by the Science Fund of the Republic of Serbia, under the GRANT No. 5151. The SmartMiner concept proposes a paradigm shift from pure technology to a Human and Data-Centric Engineering, which can be easily transferred to other industries, and develops solutions for raising the level of environmental quality in complex interactions between physical, behavioural and organizational processes field, by matching advanced operator I4.0&5.0 and society S5.0 standards. Our original idea approval route starts with mining machinery operator wellbeing in its microenvironment and its cyclical alignment with stakeholders in value chain. The initial goal of the project is development of smart, ergonomic, non-invasive and reliable operator aid systems for regulation of physical environment job stressors - noise, human vibration, lighting, temperature, air quality, and workplace layout issues etc., which solve environmental and human health issues and influence overall performance. This goal is sustained with improvements in operator macro environment determined by organizational contextual factors which also impair sustainable development results (https://smartminer.mas.bg.ac.rs/). The project was initiated in May 2023 and will last until May 2025, so at this point, only the results developed until present date can be presented.

One of important issues, set to be addressed at the beginning stage of the project is assessment of the organizational resilience, based on the observed safety climate factors at the workplaces in the mining companies, which include heavy machinery operators and transport and logistics workplaces. This stage of the research is crucial element in the future direction of achievement of defined project goals.

Development of the digital tool to be used in assessment and measurement of the organizational resilience is presented in the remaining of this manuscript.

2 METHODOLOGY

The starting Organizational Resiliance Index (ORI) measurement model is presented on Figure 1. In that direction, building up on the starting model, the practical app is being designed that will be used to measure the ORI in any company.

The app is based on the user-friendly graphical user interface (GUI) in which the decision makers (top and medium level management structures) can directly rate offered list of safety indicators. Also, mining and transportation machinery operators will be able to rate the same offered list of safety indicators, however, using the online survey, built up using the Google forms.

To be able to create the GUI, initial research stage included extensive literature research aimed to select adequate set of questions to be included in the survey. The resulting survey is consisted of six parts. The first part of the survey is used for collecting the demographic data about respondents, such are: Age, Years of working experience, Qualifications, Position in the organization, Previous experience with injuries at work, … Second part of the survey included the questions aiming to collect the data about the organization: Number of employees, The age of the company, The industrial area of operations, …. Third part of the survey is dealing with technical factors of the working places. Two subgroups of technical factors were analysed: workplace equipment and the working environment conditions. Fourth part of the survey was dealing with investigation of human factors, classified in three subgroups: Knowledge about workplace safety, Employees motivation regarding the workplace safety issues, Accepting the regulations on workplace safety. Fifth part of the survey was dealing with organizational factors and was segmented in 8 subgroups of questions: Organizational support, Co-workers support, Superiors support, Employees engagement, Work safety training, Superiors dedication, Regulations and procedures on workplace safety, Employees encouragement towards workplace safety. Sixth part of the survey was dealing with sustainability issues of the organization, including Economic, Environmental, Social, Stakeholder and Voluntariness dimensions. Each of this subgroups consisted of 3 to 11 questions, making the total number of 71 questions in the survey.

Collected responses are stored in the Google cloud database and assessed by the GUI for the purpose to calculate the organizational resilience index from two aspects. The resilience index is calculated from the aspects of safety climate factors and from the aspects of four resilience corners. The safety climate aspects are the same as the sections of the survey (starting from third to sixth part of the questionnaire). The four resilience corners addressed are React, Anticipate, Monitor and Learn (RAML corners). Belonging of each of the survey questions in each of the resilience corners is done based on the opinions of the experts, obtained during the panel evaluation. This stage is of high importance, because accurately application of the resilience indicator measurement methodology strongly depends on this segment of the research [9]. Also, to be able to use adequate Multi -criterion decision making methods for analysis (MCDM), besides obtaining the ratings from the respondents on the present values of each of evaluated questions of the survey, it is mandatory to also obtain the importance of each of the safety climate factors. Accordingly, the respondents were asked to do two evaluations, first for the present value and second for the importance of each of the survey question. The entire procedure and methodology of resilience index calculations, based on mentioned two aspects, is described in detail in the reference [10].

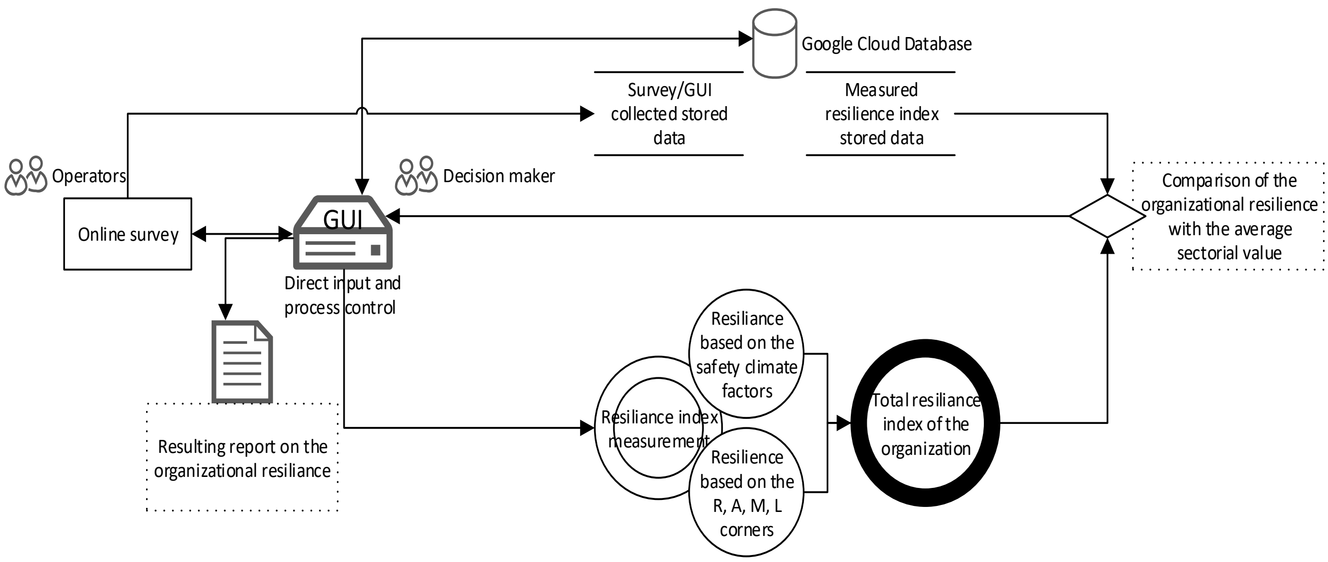

Fig. 1 Organizational Resilience Index measurement model

Obtained calculated resilience index partial values, are used for determining the overall resilience index of the organization. This value is stored in the same cloud database, together with the values calculated for previously assessed organizations. This way, using the app, based on the integrated AI models, ratings of each individual decision maker, as well as of each operator, will be used for additional updating of the database and training of the app, as well as for the comparison with the average values of all previous respondents.

Accordingly, individual ORI values calculated for any organization, will be compared to the values calculated in other organizations included in the research. There will be opportunity to make comparison among organization, without dependence on their industrial sector or to make the comparison among the organizations from same industry (sectorial comparison). This sort of benchmarking evaluation, will lead to generation of the practical advices on the operational optimization of the investigated workplaces in the investigated heavy industry sector. Those advices can be used by the organizations for their future strategic planning, as well as for operational activities targeting the improvement of their assessed level of organizational resilience.

3 RESULTS

The entire application, described in this paper, is being developed using the Python v3.10.6. The GUI is coded in the Tkinter as a Python binding to the Tk GUI toolkit [11].

The database used for this project is stored under the Google cloud console, which is open source free of charge, for up to 30 projects, of course with some limitations. Such database is limited on up to 10 reads per second and up to 10 writes per second. Considering that in this project, in its initial stage, the GUI will be used in individual organizations on the one-per-time bases, where the respondents will enter the responses through the Google form, it is not expected that this quota will be reached.

Communication among GUI and Google spreadsheets in the Google cloud database is facilitated using the Pandas – Python Data Analysis Library. The access to Google cloud and its protection is facilitated through API credentials in the form of JSON file.

At the moment of writing this manuscript, the application is still being developed. Some of the segments of the application are completed, however, due to the fact that the final product will be registered as the technical solution, its elements can not be given in the manuscript. However, until the TIL conference, most of the crucial parts of the final product will be completed, so it will be demonstrated to the conference audience in the presentation.

4 CONCLUSIONS

This paper explains the procedure of developing the software application, e.g. the tool, for measurement of the organizational resilience index, using the data obtained through the survey.

Measuring resilience through a survey involves collecting data and assessing individuals, communities, or organizations' ability to adapt and bounce back from adversity or stress. There are various methods and frameworks, available in the literature, for measuring resilience using surveys. Here is a general overview of the steps involved in creating a resilience index based on a survey, proposed in this manuscript:

1. Define the Scope and Purpose:

Determine the specific goals and objectives of intended resilience measurement. In this stage, it should be evaluated if we are interested in measuring individual, community, or organizational resilience? What aspects of resilience do we want to assess? Clarity in our purpose should be used to guide the survey design. In our case, we planned to measure organizational resilience, based on the individual opinions of its employees, so the future stages of the survey design were based on that conclusion.

2. Review Existing Models and Frameworks:

There are several established resilience models and frameworks that could be used to guide our survey development. Reviewing these existing models help us to structure our survey.

3. Select Survey Questions:

At this stage we developed and selected survey questions that align with our chosen resilience framework. These questions addressed various dimensions of industrial organizations resilience, such as technical, human, organizational factors and sustainability issues. It was important to ensure that questions are clear, concise, and easy to understand by the respondents.

4. Pilot Testing:

Before administering the survey on a larger scale, we conducted the pilot testing with a small group of respondents, to identify any issues with question clarity, length, or format. We made necessary adjustments based on the feedback.

5. Data Collection:

The survey was administered to our target population. The respondents are individuals from the mining and transport organizations. The survey included operators on the machinery, support workers, and managers of all three levels (lower, middle and top-level managers). The survey was organized using the hard copies as well as using the Google form online questionnaire. This stage of the project is still ongoing, considering that we want to ensure that we collected a representative sample to make meaningful conclusions.

6. Data Analysis:

The survey responses are being analysed using adequate statistical methods. Common statistical tools, that are used include factor analysis, regression analysis, and scale reliability assessments.

7. Scoring and Index Calculation:

In this case we are calculating overall resilience scores and scores for specific dimensions of resilience, depending on our research framework. The specific dimensions that we used are segmented as the resilience based on the safety factors and resilience based on the resilience corners. During this step we are assigning the scores to the responses based on our developed resilience model (Figure 1). This involve summing and averaging responses to specific questions and items. The resulting score is used to represent an individual's and organizational (e.g. group's) level of resilience.

8. Interpretation and Reporting:

In this stage, our model is interpreting the resilience scores in the context of our research objectives. It is considered how various factors, such as respondent's demographics or organizations descriptors, affect resilience levels. Obtained results are generated and compared with average values stored in the database. Final outcomes will be presented through reports, charts, and other visual aids to make them easily understandable.

9. Validation and Refinement:

Considering that this tool will be offered to be used by many different organizations, the database with stored survey results and calculated resilience indexes will be continuously growing. This requires continuously assess of the validity and reliability of our resilience measuring scale. In time, we may need to refine the survey questions or the scoring method based on ongoing research and feedback.

10. Use and Application:

Finally, we intend to use the resilience index measuring tool, and obtained results, to inform decision-makers, to initiate interventions, or strategy and/or policy changes aimed at enhancing resilience in the surveyed population.

At the end, it should be remembered that measuring resilience is complex operation, as it involves capturing both individual and contextual factors. The choice of resilience framework and survey design has to align with our specific research and programmatic goals. Additionally, but not less important, ethical considerations, such as ensuring participant consent and data privacy, were and still are crucial throughout the survey process.

ACKNOWLEDGMENT

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MACHINE LEARNING IN INTELLIGENT TRANSPORTATION SYSTEMS FROM THE CONTROL AND ROBOTICS PROSPECTIVE

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Abstract

Intelligent transportation systems (ITS) have become an essential component of urban planning and smart cities, playing a crucial role in enhancing traffic safety, transportation efficiency, energy conservation, and environmental preservation. ITSs encompass a wide array of services and applications, including road traffic management, traveler information systems, public transit system management, autonomous vehicles, and more. However, ITSs also produce various challenges such as scalability, diverse quality-of-service requirements, and the handling of vast data volumes generated. Some important challenges, as well as many features of ITS, are closely tied to control and robotics tasks and applications. This paper explores the use of machine learning (ML) in enabling ITS, particularly from the perspective of control and robotics. The current state-of-the-art in ML technology application for various ITS-related control and robotics solutions is considered, such as computer vision-related tasks and specialized hardware use. The primary objective has been to identify potential future directions for the implementation of ML enabled control and robotics in ITS and to ascertain how ML technology can further enhance their capabilities and efficiency.

Keywords: *Machine Learning, Artificial Intelligence, Intelligent Transportation Systems, Control Systems, Robotics.*

1 INTRODUCTION

The term Intelligent Transportation Systems (ITS) refers to the integration of sensing, communication, and information technologies into transit and transportation networks. Future smart cities are expected to heavily rely on Intelligent Transportation Systems, which will encompass a wide range of services and applications including driverless cars, public transportation system management, traveller information systems, and road traffic management, to mention a few. It is anticipated that ITS services will have a major positive impact on enhanced energy efficiency, decreased environmental pollution, transportation and transit efficiency, and road and traffic safety.

Unprecedented advancements in sensing, processing, and wireless communication technology have made it possible for ITS applications. On the other hand, because of their scalability, diversity of quality-of-service requirements, and large data generation requirements, ITS applications face a number of obstacles.

In parallel, a number of technologies, most notably cloud and edge computing, have enabled machine learning (ML) approaches to acquire substantial popularity in recent times. As a wide range of applications and services for ITS have various demanding needs, the use of machine learning for ITS has proven to be enabling technology in many cases [1][2][3]. Specifically, in addition to vehicular cybersecurity, machine learning techniques like deep learning [4] and reinforcement learning [5] have shown to be helpful in examining patterns and underlying structures in large data sets for prediction and precise decision making in ITS. The quantity of research using machine learning to provide for and optimise ITS services [5][6] has been steadily expanding over the last several years, according to statistics on research publications, which is presented in Figure 1, based on data from [1].

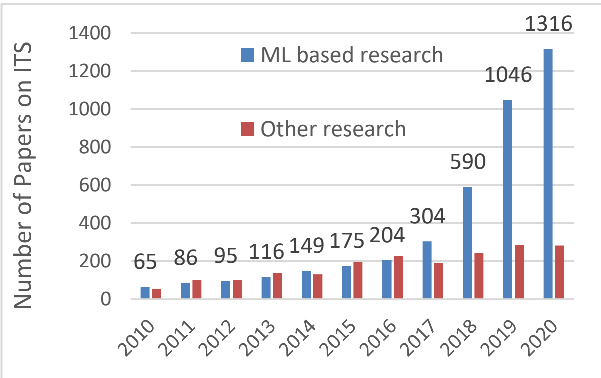

Fig. 1 *Number of publications on ITS including ML-based approaches from 2010 to 2020*

Promising research fields can be identified in addressing the unique requirements and characteristics of ITS applications through the exploration and adaptation of machine learning techniques. As a particularly important perspective, this question can be addressed from the control systems and robotics viewpoints.

The remainder of this paper is organized as follows. In Section 2, machine learning and AI development as an aid for advancement of intelligent transportation systems is discussed. Also, the evolution of computer vision (CV) in the field of ITS is considered, as well as AI hardware developments enabling ML and AI applications in ITS. In Section 3, ML developments in ITS are considered from control technology and advanced robotics prospective. In Section 4, explainable artificial intelligence for intelligent transportation systems and other research directions are considered. Finally, in Section 5 conclusions are presented together with some future pathways.

2 MACHINE LEARNING AND AI AS AN AID FOR ITS DEVELOPMENT

The domain in which transport systems operate is everything but straightforward. Many have traits that are both temporal and geographical, at different dimensions and under different situations that are influenced by outside factors including social gatherings, holidays, and the weather. However, it might be difficult to describe the interactions between variables, create generalised representations, and then use those representations to address a specific problem. These circumstances are but a small portion of the challenges that contemporary intelligent transport systems (ITS) must overcome.

ML driven tasks in ITS can be broadly classified as ML diven perception in ITS (vehicles, pdestrians, users, etc.), ML driven prediction in ITS (traffic, travel time, behaviour, road occupancy, etc.) and ML driven management in ITS (infrastructure, vehicle, resources, etc.) [1][7]. Furthermore, some classical ML tasks in ITS could be classified in the following manner:

- *Deep Learning for Image and Video Processing*: Continued advancements in deep learning algorithms, especially convolutional neural networks (CNNs), for image and video analysis and integration of deep learning models for tasks like object detection, traffic flow analysis, and pedestrian recognition.
- *Reinforcement Learning for Traffic Control*: Application of reinforcement learning (RL) to optimize traffic signal control systems, as RL can adapt to changing traffic conditions and learn optimal policies over time.
- *Predictive Analytics for Traffic Management*: Increased use of predictive analytics to anticipate traffic patterns and optimize routing and scheduling in real-time and use of time-series analysis and forecasting techniques to predict congestion, accidents, and other traffic-related incidents.
- *Autonomous Vehicles and Vehicle-to-Everything (V2X) Communication*: Integration of machine learning algorithms into autonomous vehicles for better decision-making in complex traffic scenarios and utilization of machine learning in V2X communication for improved safety, traffic efficiency, and coordination among vehicles (Figure 2).

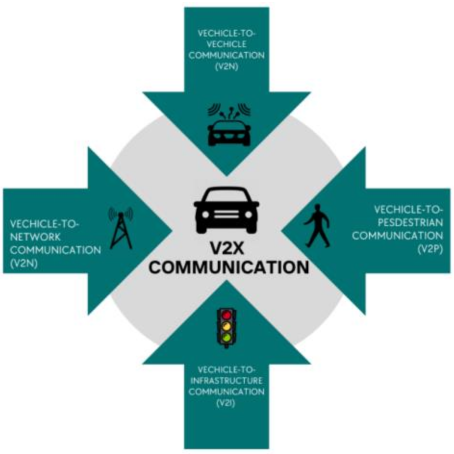

Fig. 2 *Vehicle-to-Everything Communication (V2X) protocol* [2]

- *Edge Computing for Real-time Processing*: Growing emphasis on edge computing to process data closer to the source (e.g., traffic cameras, sensors, etc.) for real-time decision-making and reduced latency.
- *Explainability and Interpretability*: Continued focus on making machine learning models more interpretable and explainable, especially in safety-critical applications like transportation, as further discussed in Section 4.
- *Robustness and Security*: Increased attention to the robustness of machine learning models in the face of adversarial attacks or unexpected scenarios in transportation systems and development of secure and resilient ML models to prevent tampering or exploitation.
- *Integration of Multimodal Data*: Combining data from various sources, such as traffic cameras, GPS, social media, and weather data, to create a more comprehensive understanding of transportation systems.
- *Human-Machine Collaboration*: Exploration of ways to enhance collaboration between AI systems and human operators in traffic management and control centers.
- *Environmental Impact Considerations*: Integration of machine learning models to optimize transportation systems for reduced environmental impact, such as minimizing emissions and energy consumption.

2.1. Computer vision applications in intelligent transportation systems

Computer vision (CV) applications are becoming more and more common in the setting of intelligent transportation systems (ITS) as technology advances [8]. The development of these applications aims to raise the intelligence, efficiency, and traffic safety of transportation systems. Developments in CV are crucial to the resolution of issues in domains that are intimately linked to the services and applications of intelligent transportation systems. Some common CV applications in ITS are listed in Table 1, based on [8].

Table 1 Computer vision applications in Intelligent Transportation Systems

CV in ITS	
Automatic Number Plate Recognition	Traffic Sings Detection and Recognition
Vehicle Detection and Classification	Pedestrian Detection
Lane Line Detection	Obstacle Detection
Anomaly Detection in Video Surveilance Cameras	Structural Damage Detection
Autonomous Vehicle Application	Other Applications

In the field of ITS, camera images are examined in CV studies to produce valuable data that may be used in a variety of situations. However, a number of undesirable weather conditions, such as heavy snowfall, rain, fog obstructing the camera, strong sunshine, and changes in image angles brought on by considerable wind-induced camera shaking, might make it challenging to take and process the picture. When consecutive images are not reliably taken from camera streams, it becomes difficult to use CV algorithms to infer significant information. Moreover, difficult backgrounds and low contrast might make it difficult to mechanically extract features from collected images.

2.2. Modern hardware devices for ML in ITS

The increasing complexity of Intelligent Transportation Systems, that comprise a wide variety of applications and services, has imposed a necessity for high-performance modern hardware devices (MHD) [9]. The performance challenge has become more noticeable with the integration of Machine Learning (ML) techniques deployed in large-scale settings. ML has effectively supported the field of ITS by providing efficient and optimized solutions to problems that were otherwise tackled using traditional statistical and analytical approaches. Addressing the hardware deployment needs of ITS in the era of ML is a challenging problem that involves temporal, spatial, environmental, and economical factors. Modern hardware devices for ML deployment in ITS can be categorized as multipurpose devices, specialized devices or hybrid devices, as presented in Table 2.

Table 2 Most common modern hardware devices (MHD) for machine learning in ITS

Modern Hardware Devices for ML in ITS	
Multipurpose Devices	MCU
	FPGA Board
	Computer Board
Specialized Devices	AG FPGA Board
	AG MCU
	GPU
	ASIC
Hybrid Devices	FPGA and MCU
	FPGA and RISC

Extensive usage of Graphical Processing Units (GPU) to run various ML algorithms has been observed in ITS literature. The main motivation behind using GPUs is their specialized computational units that play a major role in accelerating computationally demanding tasks in computer vision applications. In this respect, there has been a very wide usage of the different GPUs manufactured by NVIDIA, which offers several lines of product. Some investigations in literature used System on Chip (SoC) platforms that are usually paired with traditional general-purpose CPUs that enable Hardware/Software partitioning when it comes to implementing ITS applications.

3 ML IN ITS FROM THE CONTROL AND ROBOTICS PERSPECTIVE

Control systems technology in ITS plays a pivotal role in optimizing traffic flow, enhancing safety, and improving overall transportation efficiency. By leveraging real-time data and automation, control systems essentially contribute to creating intelligent and responsive transportation systems that meet the evolving needs of urban mobility.

Control engineering has made possible space travel and communication satellites, has assisted in the design of safe and efficient aircraft, ships, trains and cars, has helped in developing cleaner chemical processes while addressing environmental concerns. Constantly improving the quality of human life, the field of control engineering is poised to enter a golden age of opportunity and unprecedented growth being made possible by incredible advances in computer, sensor and actuator technology. The combination of machine learning and control theory involves leveraging data-driven learning algorithms from machine learning to enhance the design and optimization of control systems, enabling adaptive and more efficient control strategies in dynamic and complex environments. This combination of ML and control technology has proven to be very important and effective in enabling ITS of the new generation and beyond.

Similarly, advanced robotics in modern ITS also contributes to automation, efficiency, and safety across various aspects of transportation. Whether through the development of autonomous vehicles, robotic traffic management, robotic maintenance assistance, drone applications or security measures, robotic parking systems, last-mile delivery robots, traffic incident response or others, robotics plays a pivotal role in shaping the future of intelligent and connected transportation systems.

4 EXPLAINABLE AI AND OTHER FUTURE DEVELOPMENTS FOR ITS

The explainable artificial intelligence systems can unbox the potential of black-box AI models and describe them explicitly. The emergence of Explainable Artificial Intelligence (XAI) has potential to enhance the lives of humans and envisioned the concept of smart cities using informed actions, enhanced user interpretations and explanations, and firm decision-making processes. Various societal, industrial, and technological trends initiate the drive towards XAI for ITS and smart cities.

Explainable AI in development of ITS and smart cities plays a crucial part. Recent applications based on deep learning, big data, and IoT architectures need intensive use of complicated computational solutions. Since these systems are currently mostly closed to users, they are in most cases called black boxes. People will fear that their tools may be untrustworthy if this is true. In the last few years, attempts have been made to solve this problem using XAI methodologies to make things more transparent. The difference between traditional AI and XAI solutions is illustrated in Figure 3.

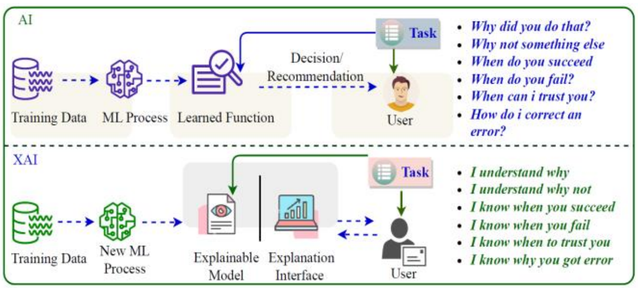

Fig. 3 *Difference between methodology of AI and XAI* [12]

Still, understanding the mathematical underpinnings of existing machine learning architectures may only provide insights into how and why a result was obtained, not into the inner workings of the models.

Apart from explainable AI, some other research directions can be marked as potentially important for further ITS development. Those include but are not limited to:

- *Responsible AI development for ITS*, which refers to the development and deployment of artificial intelligence ITS systems in a way that prioritizes ethical considerations, fairness, transparency, accountability, and the well-being of individuals and society.
- *Transfer learning for ITS* [13], which denotes a machine learning technique where a model trained on one task is repurposed or fine-tuned for a different but related task, leveraging knowledge gained from the initial training to improve performance on the new task.
- *Federated learning for ITS* [14], which is a machine learning approach where a model is trained collaboratively across decentralized edge devices or servers, allowing the model to learn from locally stored data without exchanging raw data, thereby preserving privacy and reducing the need for centralized data storage.

Besides aforementioned research directions, future trends in ML for intelligent transportation systems encompass higher dimension of perception and prediction, deeper understanding of ITS environment, fully cooperative ITS, social transportation, integrating UAVs in ITS, secutirity and privacy enhancements, 6G ITS and others.

5 CONCLUSIONS

Intelligent transportation systems are likely to be an integral and crucial component of tomorrow's smart cities and will include a variety of services and applications. In enabling ITS in the recent past, present and likely future due to ever increasing complexity of the tasks involved, a crucial role belongs to the machine learning approaches and artificial intelligence in general.

Future trends in development of ML solutions for ITS include particularly explainable AI approaches, but also concepts of responsible AI, transfer learning, federated learning, and others.

Many recent advances and future prospects for machine learning and artificial intelligence applications in ITS can be viewed as direct solutions of problems originating from novel control systems development and as application of advanced robotics concepts and solutions.

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OPERATIONAL OPPORTUNITIES FOR REDUCING AIRCRAFT FUEL CONSUMPTION

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Abstract

Through economic and environmental effects, the rational use of energy resources in air transport represents an important segment of general efforts in global environmental protection. Increasing the energy efficiency of transport aircraft is a complex problem, and the basis of this task is the consumption reduction of jet fuel, designed for use in aircraft powered by different types of gas-turbine engines. Practically every element of the air transport system has a certain influence in this domain, starting from the manufacturer with the design and production of the aircraft, through the influence of an operator on the efficiency that the aircraft shows in the airlines, to the influence of the traffic environment and air traffic control. In this paper, special attention is given to the direct influence of the operator on the achieved aircraft fuel efficiency in the fleet. The selection of primary activities that can be carried out in the operational environment to reduce fuel consumption was made, by considering the operating processes within the framework of the performance and control of the technical condition of the aircraft. Several activities can contribute to reducing consumption, such as control of mass and position of the center of gravity, aircraft ground operations management, control of the technical condition of aerodynamic and control surfaces, as well as control of the operation of aircraft systems and instruments. By analyzing the mentioned activities, it was shown that numerous items have an influence on fuel consumption. A key element in identifying priorities when taking appropriate measures is the assessment of fuel consumption reduction based on flight parameters data. Based on this data, an evaluation of possible fuel savings was made for different types and categories of aircraft. It has been shown that the cumulative effect of individual small contributions can result in a significant reduction in fuel consumption.

***Keywords**: aircraft, fuel consumption, performance, technical condition, operational environment.*

1 INTRODUCTION

During the last century, the aviation industry experienced a huge development, so today it has a significant impact on the entire world economy and largely determines the level of overall technological development. From zero at the very beginning of the last century, air traffic at the end of the 20th century accounted for about 17% of the global air passenger traffic volume, with the projection to grow by more than 35% in 2050 [5]. Due to the COVID-19 pandemic, this projection has not been achieved and the number of Revenue Passenger Kilometers (RPKs) in April 2020 rapidly dropped by more than 94% [1] in comparison to April 2019 (Figure 1).

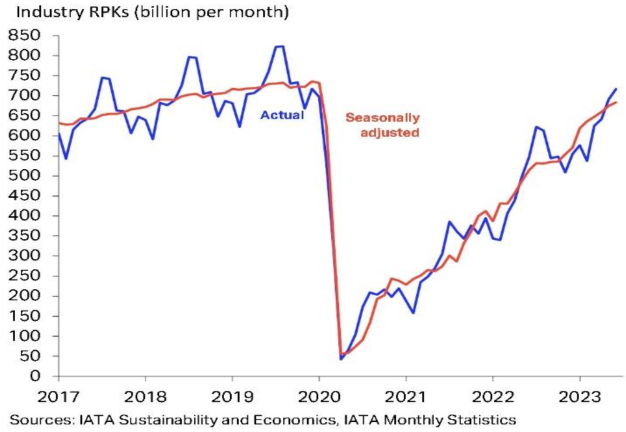

Fig. 1 *Revenue passenger kilometers (RPKs) per month*

However, with the mitigation and final cancelation of COVID-19 restrictive measures, air passenger traffic had a dramatic recovery, so that in the first half of 2023. number of global RPKs reach 94.2% of pre-COVID level. For example, from January to June 2023. global RPKs rose almost 50% compared to the same period in 2022.

With this intensive growth in the number of flights and passengers, aviation companies are constantly forced to improve the efficiency of their operations, primarily due to the increase in Direct Operating Costs (DOC).

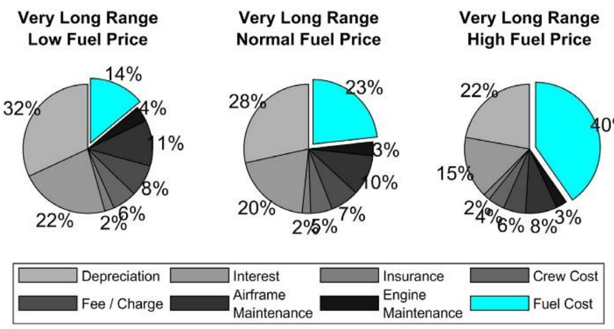

Fig. 2 *Direct operating costs breakdown of Boenig 747-8*

Direct operating costs are related to the realization of the aircraft flight and include airframe and engine maintenance, fuel and oil, costs of crew and attendants, insurance and financing, depreciation, airport and navigation fees, etc. Fuel costs are one of the biggest items in the company's business, which is directly related to the aircraft type and fuel price. For a typical airliner, fuel costs account for 23% of the direct operating costs [2], but they can grow up to 40% for wide-body aircraft such as B747-8 at very long route distances (Figure 2) for the high fuel prices [3].

During the 1990s crude oil price was more or less stable, but from the beginning of the 21st century, different geopolitical crises (September 11, the war in Afghanistan, Iraq, Syria, etc.) and global market demands has caused wide and rapid fluctuation of crude oil price (Figure 3).

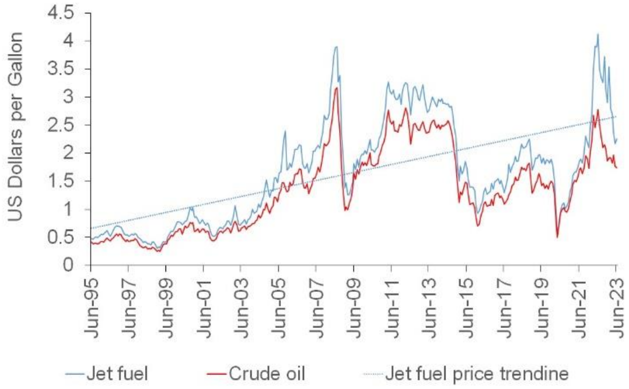

***Fig. 3** Fluctuation of crude oil and jet fuel price*

Compared to previous years in the early 2000s, the price of crude oil increased by over 100%, which affected all derivatives including jet fuel. The increase in fuel prices has a complex impact on the airline business in two related ways:

- directly through higher DOCs, usually compensated by higher ticket prices or air freight cargo costs, and
- indirectly through the reduction of the passenger and cargo load factor, caused by higher transportation costs.

That compels airlines to take a serious approach to the problem of fuel economy, and further analysis of aircraft fuel consumption reduction methods in the operational environment is a subject of particular interest for all airlines.

2 REDUCTION OF FUEL CONSUMPTION

Fuel consumption reduction means managing the operation and condition of an airplane to minimize the fuel used on every flight [4], which is the basic problem in fuel planning. Adequate fuel planning as well as optimal aircraft utilization lead not only to fuel reduction, but also to total direct operating costs reduction. Table 1 shows how a 1% reduction in fuel consumption is reflected in the total fuel savings of an airplane for typical utilization rates on an annual basis [4].

Table 1 Fuel savings for 1% of fuel consumption reduction

Airplane type	Fuel savings kg/year/airplane
B777	214000 ÷ 276000
B767	92000 ÷ 123000
B757	77000 ÷ 107000
B747	307000 ÷ 414000
B737	46000 ÷ 77000
B727	92000 ÷ 122000

From the airline's financial point of view, reducing fuel consumption can be defined as the synchronization of operations and conditions under which each flight is carried out with the aim of minimizing the total flight costs [4].

How these savings will impact the airline's business depends on the fuel prices in the market. Fuel prices are variable and thus pose a challenge to fuel planning policies, such as deciding on the amount of fuel to carry and when to refuel at either the departure or destination airport. Evaluating the worth of fuel consumption reduction requires considering both the current fuel price and the cost of fuel-saving measures, which is not the subject of this paper.

The key factor in achieving fuel savings is related to the monitoring and managing processes involved in aircraft operation that can be realized by the airline. The analysis of process management during aircraft operation, according to the areas of application, can be divided into two main segments based on their application:

- aircraft pre-flight and in-flight procedures, and
- aircraft and engine technical condition control.

It should be emphasized that there are certain limitations in undertaking some specific procedures to reduce consumption, which is primarily related to the issue of flight safety and prevention of potential incidents.

3 AIRCRAFT PRE-FLIGHT PROCEDURES

The pre-flight measures that can be implemented in order to reduce fuel consumption represent the adjustment of certain ground operating procedures. These procedures refer to the control of the mass and position of the center of gravity, aircraft taxiing operation, and the use of the Auxiliary Power Unit (APU).

3.1. Aircraft mass

Aircraft mass is an important parameter in flight planning. Range, cruising altitude, and speed are parameters that directly depend on the mass of the aircraft. As the mass of the aircraft increases, the fuel consumption also increases. Therefore, when planning a flight, it is necessary to match the capabilities of the aircraft with the operational requirements. The modern market of passenger service dictates an increase in payload due to baggage, duty-free goods, and other things offered to passengers on the flight.

For fuel consumption reduction through the aircraft mass, special attention must be paid to the landing mass of the aircraft. The landing mass reduction contributes significantly to the reduction of fuel consumption. A reduction of 1% of the aircraft landing mass can reduce trip fuel consumption by up to 0.75% in the case of high bypass-ratio engines, or up to 1% in low bypass-ratio engines.

Aircraft landing mass reduction can be achieved by the reduction of some individual components of the Operational Empty Mass (OEM). Operational empty mass, in addition to the mass of the aircraft structure, powerplant, equipment, and systems (which are an integral part of the aircraft), includes standard accessories (emergency equipment, buffet structure with food containers, etc.), and operational accessories (mobile buffet equipment, flight manuals, crew and their baggage, etc.), but does not include fuel. It is possible to optimize OEW by an adequate selection of flight equipment, as well as content for passenger entertainment during the flight. It is also important not to carry empty containers, unnecessary emergency equipment, and too much water on the flight because all of them add to the weight of the plane.

There are a number of items that can be considered as an opportunity for OEM reduction (Table 2).

Table 2 Examples of OEM reduction opportunities

Opportunity	Comments
Potable water reduction	It is necessary to optimize the amount of potable water for each flight. For example, by introducing the practice of partially filling the aircraft water tanks, with water filling of 75% of the tank capacity, the estimated savings can be up to US$ 8 million annually.
Duty-free items reduction	Commercial effects should be considered.
Removing galley components	For short-haul operations, some galley components (water heaters, coffee makers, etc.) may not be needed.
Waste water tanks emptying	Many companies are introducing the practice of emptying the aircraft waste water tanks after each flight, which was not common practice before.
Cleaning aircraft interior	Minimizing mass increase due to accumulation of dirt.
Passenger entertainment items reduction	The mass of newspapers, magazines, catalogs, flyers, and related material in seatback pockets, can be considerable.
Replacement of paper flight crew manuals with electronic devices	Alaska Airlines crews no longer bring manuals onto the plane, which the company estimates saves up to US$30,000 annually.

The possible contribution of these mass reductions is shown in Table 3, where the block fuel savings (in percent) are expressed per 1000lb (454 kg) of Zero Fuel Mass (ZFM) reduction [4]. It should be noted that ZFM is the sum of the operational empty mass and the payload mass.

Table 3 Contribution of mass reduction on block fuel savings

Aircraft type	Block fuel saving [%]
B737-3/4/500	0.7
B737-6/7/8/900	0.6
B767-2/3/400	0.3
B777-200/300	0.2
B747-400	0.2

The airlines often introduce their own ways of reducing OEM, and not all opportunities are applicable to different aircraft categories, types, and versions. Some of the measures implemented by companies may be addressed to specific operating conditions and seem negligible, but they certainly contribute to fuel reduction.

3.2. Center of gravity control

The position of the aircraft's Center of Gravity (CG) is of great importance for the aircraft's stability, and the main task of aircraft weight and balance service is the positioning of CG between the forward and rearward limit. By redistribution of the payload (passengers, passenger baggage, cargo), the position of CG can be near forward or near rearward limits.

Depending on the aircraft type, the position of CG near to forward limit can increase trim drag up to 3% in comparison to the rearward position [5]. In Table 4, the position of CG is expressed in a [%] of the Mean Aerodynamic Chord (MAC).

Table 4 Trim drag increment ΔC_x

B737-300		B777-200	
CG position [% of MAC]	ΔC_x	CG position [% of MAC]	ΔC_x
8÷12	+2%	14÷19	+2%
13÷18	+1%	20÷26	+1%
19÷25	0	27÷37	0
26÷33	–1%	38÷44	–1%

Contrary to the previous, with the further rearward CG position, the downward balance force required from the horizontal stabilizer decreases, thereby lowering the lift force on the wings resulting in a decrease of the drag force.

Therefore, from the aspect of fuel savings, the most favorable position of CG is near the rearward limit when the trim drag increment has a negative value, i.e. there is a decrease in the aerodynamic drag of the airplane.

3.3. Ground operation and engine starting

Ground operations and engine starting refer to the activities that need to be performed in order for the aircraft to take off safely and on time. From the point of view of fuel savings, considerable attention should be paid to taxiing, Auxiliary Power Unit (APU) use, and engine starting.

Taxiing can sometimes require a long drive from the terminal to the PSS, and fuel savings can be achieved by using the shortest possible routes, as well as using as low thrust with minimal braking as possible in taxiing.

There is the possibility of using one engine for taxiing twin-engine aircraft, or two engines for four-engine aircraft, which can enable fuel savings. However, the decision of whether to use such procedures or not is very complex and represents a balance between fuel economy and safety. Therefore, airlines that decide on this type of savings, must define their own taxiing policy based on the airport infrastructure (aprons, taxiways, and runway position).

Anyway, if a long taxiing of the aircraft from the terminal to the runway is unavoidable, it is necessary to consider taxiing with only one engine and then subsequently starting another engine during taxiing. As example, in table 5 are shown the advantages in fuel savings with one engine out for 8 of the 12 minutes total taxiing time [6].

Table 5 Fuel savings with engine out taxiing

Aircraft types	12 min. taxi (all engines)	12 min. taxi (8 with engine out)
A310	240 kg	160 kg
A318	120 kg	80 kg
A319	120 kg	80 kg
A320	138 kg	92 kg
A321	162 kg	108 kg
A330	300 kg	200 kg
A340-200/300	300 kg	250 kg
A340-500/600	420 kg	350 kg

Reduction of fuel consumption can be achieved even before the flight begins, by starting the engines in time, at the latest possible, in coordination with airport air traffic control. If the use of the ground electrical system is available, it is recommended to minimize the use of the APU.

APU fuel consumption (at sea level, under ISA conditions) depends on the APU type and ranges from 60÷80kg/h if there is no additional power supply to 110÷160kg/h if cabin pressurization, electric power supply, or engine start is performed. If possible, aircraft air conditioning and engine starting using APU should be avoided. The average fuel consumption of APU under normal operating conditions of CFM56 engines, one of the common types of engines on A320 and B737 aircraft, is more than 110 kg/hour.

If the plane has a night stop or if there is a long time between landing and the next take-off, it is advisable to use ground generators. It should be noted that one extra minute of APU use per flight with a consumption of 180kg/h requires an additional 3000kg of fuel per year for just one aircraft.

Shutdown of the ground units and start of the APU must be coordinated with airport traffic control because every minute of non-use of the APU can result in an annual saving of 2000-4000kg of fuel depending on the APU type. However, in cases where the aircraft has a short stay at the airport (less than 45 minutes), there is an advantage to using APU. Also, it is necessary to take into account the restrictions related to the use of APU that many countries have adopted.

It is very difficult to define when it is better to use APU and when ground power because it depends on several parameters. Therefore, airlines are left to define the most economical solution depending on their own needs.

4 AIRCRAFT IN-FLIGHT PROCEDURES

Considering the standard flying techniques, there are many different parameters such as thrust settings, flying speed, altitude, aircraft configuration, wind speed and direction, etc. that have a big influence on fuel consumption. A key factor in in-flight fuel economy and costs is the flight crew's adherence to the flight plan based on the operator's priorities. In order to achieve as much as possible fuel economy in in-flight procedures, is necessary to review all flight phases.

4.1. Take-off and climb

During take-off and climb, aircraft engines operate at the highest thrust rating with high fuel consumption. Take-off thrust setting and selection depend on many elements as aircraft configuration and status, actual take-off mass, terrain, weather, airfield altitude, runway condition, etc. Take-off performance and fuel consumption also depend on engine bleed air distribution to the air conditioning system or anti-icing system and using APU bleed air.

Based on data from the Airplane Flight Manual (AFM), it is possible to create flight profiles for non-standard take-off and climb procedures. Non-standard procedures often contain flying techniques that can result in improvements primarily in terms of fuel consumption reduction.

As specified in the AFM, the take-off procedure performed with increasing take-off speed can result in an important improvement in climb performance.

The analyses show that if there is a sufficient length of runway it is possible to allow unstick at speeds higher than lift-off speed (v_{LOF}), i.e. the airspeed at which the airplane first becomes airborne. Such a procedure leads to a reduction of the fuel consumed in the climb during the further phase of flight, because the aircraft reaches the speed for climbing on the route in a shorter time, even though its thrust is at the maximum take-off thrust. The take-off phase is completed in a shorter time and less fuel is consumed in take-off.

Another important procedure that is widely used for take-off is the use of derated thrust. Derate take-off thrust procedure can be used in the case of a smaller quantity of payload or carrying a smaller quantity of fuel for flight (short-haul flights), with a potential fuel savings goal. For example, in the case of B737-300 aircraft with CFM56-3-B1 engines and a load factor of 66% on a line of 1200 NM, it is possible to achieve a fuel consumption reduction of 7.7% by applying derated thrust [5].

Also, there is an option to apply the climb derated thrust procedure if the atmosphere and obstacle conditions permit (with approval by air traffic control). But, the use of derated take-off and climb thrust tends to slightly increase fuel consumption in comparison to full take-off and climb thrust, because the increased climb time cancels a slight fuel reduction induced by the thrust derating.

However, the derate thrust procedure saves engine life and thus reduces fuel consumption over time. For example, a 1% reduction from full take-off thrust will result in a 10% saving in engine life [7].

Derate thrust procedures must go through a licensing process and a maximum level of thrust reduction for takeoff must be determined. That process is carried out by the aviation authorities in cooperation with the engine and aircraft manufacturer. The maximum thrust reduction percentage must be such that the pilot can at any time, in case of danger, raise the thrust to the Take-Off/Go-Around (TOGA) level.

Considerable influence on fuel consumption on take-off and climb phases have flaps settings and speed management. It is necessary to follow standard procedures for flaps deflection during the take-off and begin up on flaps retraction as soon as possible once the aircraft is airborne. Also, differences of ±30 kt from optimized speed for a climb to FL 350 can increase fuel consumption up to 130 kg.

There are opportunities to optimize the vertical climb profile, with the goal of fuel consumption reduction. Fuel consumption may be reduced by performing Continuous Climb Operation (CCO) to the initial cruise altitude. This procedure requires coordination between the airport, terminal area, and an Air Navigation Service Provider (ANSP).

4.2. Cruise

The climb phase can have a large effect on a cruise, especially on short-haul flights. An analysis of the interaction between these two flight phases must be performed, in order to avoid the trap of saving fuel only in climb, which can result in a short cruising phase and increased fuel consumption.

The airplane climbs to the cruise altitude which is the most economical to fly in terms of fuel consumption and time. If the cruise phase is shortened as a result of a long climb, that can have the effect of increasing the overall fuel consumption for the entire flight.

Choosing the optimal flight level is a very important element in any flight plan in terms of fuel consumption. For instance, an increase in fuel consumption for B737-300 due to cruising at non-optimal altitudes for Long Range Cruise (LRC) and Mach number M=0.74 is shown in Table 6 [4].

Table 6 Increase in fuel consumption in percent at non/optimal cruise altitudes

Non-optimal altitudes	Increease in fuel consumption	
	LRC	M=0.74
2000 ft above optimal FL	1%	1%
optimal FL	0	0
2000 ft below optimal FL	1%	2%
4000 ft below optimal FL	4%	4%
8000 ft below optimal FL	10%	11%

LRC mode of flight ensures minimal fuel consumption and the LRC speed provides 99% of the maximum specific range. There is also a climbing technique with a controlled increase in fuel consumption, whereby a flight profile is selected to maximize the cruise length. Then in the cruise phase, High Speed Cruise (HCS) mode is applied to compensate for the fuel loss from the previous climb phase. Also, on long-haul flights in the cruise phase, it is possible to apply the step climbing technique in order to increase fuel efficiency.

4.3. Descent and landing

In the descent phase fuel consumption is less than climb and cruise fuel consumption. The engine thrust setting in the descent is idle, and the speed is controlled by aircraft attitude. Regardless of that, there is a great opportunity for fuel saving in the descent phase. To achieve an efficient descent, it is necessary to preserve an uninterrupted profile of the flight without the use of thrust, level flight, or speed brake, until the final approach.

Significant savings and other benefits can be achieved by early and timely initiation of the Continuous Descent Operations (CDO) procedure, ideally from cruise flight levels. Fuel savings that can be realized by the application of the CDO procedure range from 50kg to 150kg per flight. The estimation of the European Civil Aviation Conference (ECAC) is that the CDO procedure implementation could reduce annual fuel costs by over 100 million Euros.

5 TECHNICAL CONDITION OF AIRCRAFT

One of the effective methods for fuel consumption reduction is the prevention of excessive deterioration of the aircraft's technical condition. The deterioration of the technical condition takes place due to the different influences during the aircraft operation, which mainly results in wear and tear.

A technical condition is usually considered from the aspect of flight safety, however, there are a large number of elements whose condition change primarily refers to the deterioration of performance and reflects an increase in fuel consumption. During regular operations, the efficiency of a new aircraft decreases by 1% every 1000 cycles with a later tendency to stabilize the increase in fuel consumption by up to 7% [7]. That suitably indicates the importance of aircraft maintenance in terms of reducing fuel consumption.

The increase in fuel consumption due to the technical condition of the aircraft is caused primarily by the deterioration of the airframe and engines. Also, the condition of certain aircraft systems, as well as the accuracy of some cockpit instruments, can also have a significant contribution to the increase in fuel consumption.

5.1. Airframe

One of the fuel-saving methods in airlines is improved airframe maintenance with the main goal of reducing aircraft drag and thus reducing required thrust, which results in fuel consumption reduction.

During aircraft operation, the airframe is exposed to different influences due to weather conditions, precipitation, small service incidents, wear, etc. The occurrence of aerodynamic deterioration caused by any reason leads to small increases in aerodynamic drag and if maintenance actions are not taken, cumulative effects lead to an increase of up to 2% in aerodynamic drag for 5 years [8].

Every 1% increase in drag, depending on the type of aircraft and the flight time, can significantly contribute to the amount of fuel consumed. For example, for a B737 aircraft with an annual flight time of 2500 hours, a 1% increase in drag leads to an increase in annual fuel consumption of approximately 76000 to 77000 kg or a reduction in payload equivalent to more than 12 passengers [9].

Approximately 96% of the total drag of the aircraft belongs to components that cannot be avoided and by physical source can be divided into two groups:

- friction drag, and
- pressure drag.

The friction drag depends on the type of flow (laminar/turbulent), the thickness of the boundary layer, and the roughness of the surface.

The pressure drag includes other components (induced drag, wave drag, form drag), which depend on the pressure distribution around the airframe components. The remaining up to 4% belong to different forms of parasite drag known as excrescence drag [4] which can be reduced by proper airframe maintenance.

The excrescence drag is the additional drag sum of various deviations from a smooth and sealed external surface on the airframe. From the aspect of maintenance, the following can be distinguished [5]:

- misrigging of flight controls and moving surfaces,
- mismatches on the airframe surfaces,
- gaps and missing aerodynamic seals, and
- physical condition and surface roughness.

Most of these effects during the airframe inspection can be easily detected during aircraft visual checks, but the aerodynamic inspection should be done in flight. Regarding from causes of aerodynamic deterioration (wear and tear, accumulation of dirt, abrasive, seal rubber aging), the problem of the excrescence drag caп be complete or partially removed through a regular maintenance.

Incomplete retraction of the control and other moving surfaces leads to disturbances in airflow and therefore to an increase in drag. About the control surfaces on the wing or tail (Figure 4), there are additional effects due to the creation of small aerodynamic moments, which may require additional trimming and the generation of excessive input signals in the autopilot system.

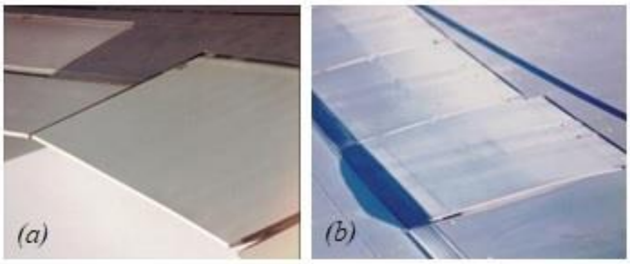

Fig. 4 *Misrigging of aileron (a) and spoiler (b) [8]*

The increase in fuel consumption, as a consequence of the previously described aerodynamic effects, depends on the height of the gap between the control surface and the basic aerodynamic contour, the size, and type of the control surface, as well as the type of aircraft.

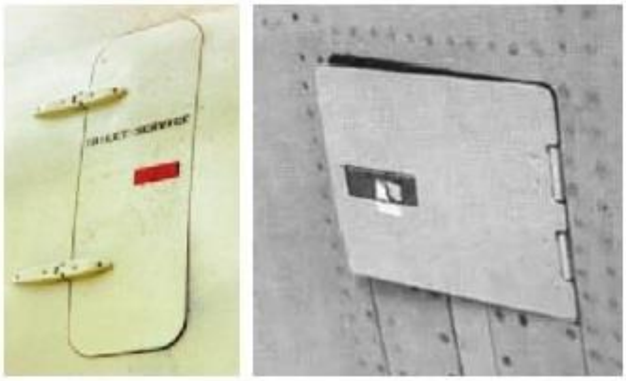

Fig. 5 *Mismatched access doors [8]*

Mismatched and uneven surfaces on the aircraft usually lead to step transitions, which, regardless of how they are turned in relation to the airflow (forward or backward), cause the appearance of turbulent flow, i.e. an increase in drag. These surface irregularities can occur both at panel joints and access doors (Figure 5). Stepped transitions on the front parts of the aircraft cause some losses, with over 0.3% increase in fuel consumption.

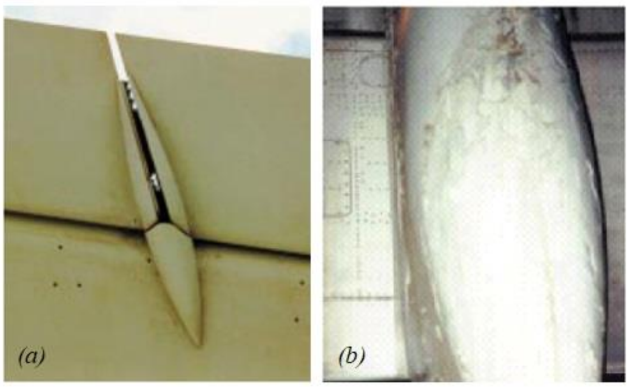

Fig. 6 *Damaged flap seal (a) and skin roughness (b) [8]*

The condition of seal on the moving parts, especially on the wing section (Figure 6), where high and low pressure areas are established, affects on the aerodynamic efficiency. The force of aerodynamic lift depends on the achieved pressure difference between the upper and lower surfaces of the wing, and the local poor sealing of the moving sections leads to airflow from the high pressure to the low pressure zone. This reduces the lift force and efficiency of the wing, which is related to the aerodynamic drag increase.

The problem of seal damage on unmovable parts is primarily related to doors in pressurized zones of the fuselage. Air leakage due to poor sealing around passenger or cargo doors from pressurized areas into the outside atmosphere leads to two different forms of losses:

- the slight pressure drop in the pressurized part of the aircraft caused by air leakage must be compensated by the increased engine bleed air, which directly affects the drop in thrust and the increase in specific consumption of the engine, and
- the outside airflow at the leakage point leads to disturbances in the flow and increases the drag.

Certainly, skin roughness due to dirt, paint peeling, abrasion, bad painting, etc. has an important influence on friction drag (Figure 6). Also, skin dents due to bird strikes and handling carelessness can also be treated as an influencing factor of surface friction drag.

Based on data provided by IATA [7] and Airbus Industrie [8] estimation of the influence of airframe deterioration on an increase in fuel consumption (Table 7) is done [9].

Table 7 Effect of airframe deterioration on fuel consumption

Airframe deterioration	Item	Increase in fuel consumption
Misrigging	Spoiler	0.06%
	Slat	0.06%
Absence of seal	Flaps & Ailerons	0.13%
	Slat	0.06%
Surface mismatch	Passenger front door	0.08%
	Forward cargo door	0.04%
	Nose landing door	0.04%
Skin roughness	Upper wing skin	0.06%
	Total	0.53%

In the scope of the aerodynamic deterioration and fuel consumption, there are no individual items that have a large influence on fuel consumption increase (Table 8). However, the combined effect of multiple factors on the overall result can be significant. For example, Boeing B737-300, with an average flight length of 1300 km, consumes about 4500 kg of jet fuel per flight. Due to airframe deterioration, the increase in fuel consumption is up to 24 kg per flight. For yearly utilization of 1400 flights, total fuel savings is up to 33600 kg/aircraft/year.

5.2. Engine

The leading cause of decreasing aircraft fuel efficiency is engine performance deterioration, which is detected through an increase in Specific Fuel Consumption (SFC). Increase of SFC depends on many factors such as flight time, number of cycles, leg time, operational environment, etc., and can be up to 1.5% per 200 flight hours.

There are several areas in the engine that affect the increase in SFC. In modern turbofan engines, the primary causes of the SFC increase are the erosion of fan and compressor blades, changes in the radial clearances on the seals between the rotor and stator parts or rub strip wearing, and the dirt accumulation on the blades and the contamination of the flow section of the engine.

Fan and compressor blades in turbine engines are exposed to long-term erosion, and if carbon particles appear in the combustion process, erosion of the turbine blades is possible. Also, erosion is a cause of blade tip ring seal wear, which leads to increased radial clearance and reduced module efficiency. Erosion can change the shape of the airfoil of the blades and cause damage to the final aerodynamic surfaces, with a gradual aerodynamic performance decrease. Tests carried out by Pratt & Whitney showed that by fan and compressor blade shape control it is possible to reduce the specific fuel consumption by 2÷2.5% in comparison to a standard overhaul.

By improving the sealing at the tips of the compressor and high-pressure turbine rotor blades, the specific fuel consumption can be significantly reduced, and the engine Time On Wing (TOW) can be increased. One of the reasons for engine removal is Exhaust Gas Temperature (EGT) margin reduction which is mainly caused by deterioration of high pressure turbine components. EGT is used as an indicator of the quality of high pressure turbine operation, and the main cause of the hot section components deterioration is the increase of clearance at the blade tips. SFC and EGT are directly related to the high pressure turbine blade tip clearances. It was found that each increase in HPT blade tip clearance of 0.001 in, resulted in an increase in SFC of approximately 0.1%, and EGT by 1ºC. Therefore reducing HPT blade tip clearance by 0.010 in would reduce SFC by approximately 1%, and EGT by 10ºC [5].

Dirt accumulation is mainly formed on the fan blades and compressor and causes a decrease in airflow and efficiency. The decrease in airflow is characterized by an increase in engine speed, while the decrease in efficiency is expressed by an increase in EGT and SFC.

Engine washing on a wing at regular intervals ensures good fuel economy. Washing is a simple procedure, where one part of the activity can be done manually. To perform this activity, which lasts 3÷4 hours, two mechanics are needed, and its application can improve the SFC by up to 1.5%.

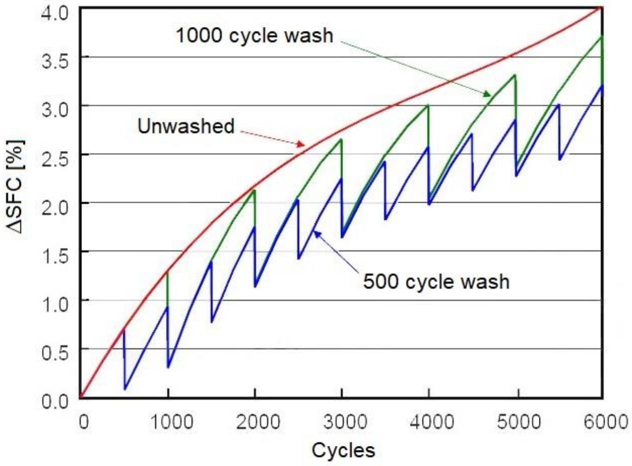

Fig. *7 Influence of engine water washed frequency [8]*

For instance, for Boeing B777 with a flight leg time of 6.5h and 620 cycles per year, fuel savings can be between 60000 and 90000 kg. Therefore, by regularly washing the engine between scheduled shop visits it is possible to restore SFC which is shown in Figure 7 [4].

During aircraft operation, causes that lead to severe engine damage are relatively rare. Therefore, from the regular maintenance point of view, the estimation of the fuel consumption reduction is based on the long-term causes of engine deterioration. These are primarily the erosion of the fan blades, rub strips, and accumulation of dirt.

Table 8 Block fuel savings

Item	Condition	Cruise ΔSCF	kg/engine/year
Fan blades	Leading edge erosion	0.6%	up to 40000
Fan rubstrip	Wear resulting in increased tip clearance	0.3%	up to 20000
Fan and Compressor airfoils	Accumulation of dirt	1%	up to 67500

The estimated fuel penalty for Pratt & Whitney JT9D-59A engine gas path deterioration [10], with annual engine operation of 2000 h at an average flight length of 1000 nm, is shown in Table 8.

5.3. Systems and instruments

Systems and instruments operation control play an important role in improving fuel efficiency. From the view of fuel saving, very important is ensure good sealing in systems with compressed air and adequate accuracy of speed measuring instruments.

Pressurized air is used in the operation of many systems, such as air conditioning, pressurization, anti-icing, de-icing, engine start, hydraulic reservoirs pressurization, water system pressurization, etc. Pressurized air is obtained by extracting so-called bleed air from some engine compressor stages and APU compressor. Bleed air typically has a temperature of about 250 ºC and a pressure of approximately 3 bar.

The distribution of bleed air is accomplished by pneumatic system ducts, valves, and regulators for bleed air flow control and distribution to various aircraft systems. Flanges, gaskets, and joints are used to connect various sections of pneumatic system lines. Undesirable air leaks can occur on the seals of pneumatic joints if they are not properly mounted or maintained. Also, air leaks can occur at the bleed valves, which can be observed by the performance trends monitoring during the flight.

Bleed air leaking from the pneumatic system leads to an increase in fuel consumption, due to compensation for engine performance decline. Also, bleed air leakage leads to a shortening of the interval between engine shop visits and an increase in the maintenance costs of the pneumatic system.

Repair of leaking bleed valves is generally a simple procedure that can save up to 2.5% of specific fuel consumption. Pneumatic system air leaks are also important for fuel saving, and practice shows that pneumatic liking account for about one-third of ATA36 operational failures.

A worn-out Air Cycle Machine (ACM) in an air conditioning system may require additional pneumatic power for operation. That results in additional fuel consumption due to providing more bleed air from the engine's compressor to meet the demands of the air conditioning system.

With regular inspections and control of the ACM condition, it is possible to eliminate the influence of ACM worn-out to the increase in fuel consumption.
In some aircraft, during the landing approach (throttle back) with the operational ACM and activated pneumatic anti-icing system, due to pressure loss caused by leaks additional power is required to meet the pneumatic requirements. This can change the landing approach profile, which can further increase fuel consumption.
The instrument's accuracy affects directly the aircraft's actual flight performance. If is instrument's accuracy outside of the range of tolerances, by displaying incorrect values the pilot gets the wrong information about the flight parameters, which finally leads to an increase in fuel consumption. By calibrating aircraft cockpit instruments, good performances of the aircraft are ensured. Typical ranges of instrument accuracies are shown in Table 9.

Table 9 Aircraft instruments accuracy

Mach number (M)	±0.005
Airspeed	±2 Knots
Altitude	±50 feet
Total Air Temperature (TAT)	±1°C
Fuel flow (FF)	±0.5÷1%
Engine Pressure Ratio (EPR)	±0.005÷0.01 (0.5÷1% trust)

During operation, the Mahmeter reading tends to move towards the lower end of the tolerance range. If the Machmeter shows a 0.01 lower value and the crew flies at a constant cruise Mach number, the aircraft will actually fly 0.01 Mach faster. For example, flying at a Mach number 0.01 higher than planned, on a B737-400 can lead to an increase in specific fuel consumption by more than 1% [4].
If the indicated speed is 1% lower, the aircraft will actually move at a speed higher by 1%. That will lead to an increase in fuel consumption due to the increase in the value of the aircraft drag force by 2%.
An EPR indicator that is out of calibration by 0.01 EPR can have an impact of up to 2÷3% on cruise fuel if EPR is used as a primary parameter in cruising.
Therefore, it is very important to have a maintenance program that includes periodic calibration of the instruments.

6 CONCLUSION

The fact that fuel today accounts for almost 25% of the direct operating costs and high prices of jet fuel forces airlines to consider an improvement of fleet fuel efficiency as a regular task. The airline's operational opportunities for fuel consumption reduction were considered through different activities in the framework of the following domains:

- the aircraft performance through aircraft configurations in pre-flight and in-flight procedures, and
- maintenance of the airframe, engine, and aircraft system and instruments.

There are many items that can be considered in the scope of operational fuel reduction in the airline fleet, and significant fuel savings can be achieved from the summation of the many smaller fuel-saving results.

Therefore, it is necessary to create awareness that the cumulative effect of individual small contributions provides a significant fuel saving. The introduction of additional training of flight and ground personnel on fuel-saving techniques and teamwork creates the basis for achieving the strategic goal of minimizing DOC.
Continuous staff education and proper motivation policy can be a key factors in achieving a high level of fuel efficiency in aircraft operations. Whitin introduction of additional training programs, it is necessary to analyze the required training level according to the airline's needs, which for a specific case can be one of the directions of further work in this area.

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ERGONOMIC SIMULATION MODEL OF WORKING POSTURES DURING MANUAL ORDER PICKING IN WAREHOUSES

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Abstract

Manual material handling (MMH), or manual order picking in warehouses, plays a critical role in efficient distribution operations. This process can subject workers to physical stress and various musculoskeletal disorders. Since the majority of warehouses still rely on MMH operations, the optimization of this processes is vital to improve productivity, reduce errors, and enhance worker well-being. This study presents an ergonomic analysis and simulation approach to evaluate MMH processes in warehouses. Various factors are considered, such as shelf heights, container/box weights and picker capabilities. Siemens Jack software is used to create the virtual setup and assess the impact of the different variables on overall ergonomics. Based on the simulation outcomes, recommendations are provided for creating safer working environments.

Key words: *warehouse manual order picking, human factors, virtual ergonomic tools, ergonomic recommendations*

1 INTRODUCTION

The necessity for conducting this research is buttressed by an examination of prior studies in the domain of order picking activities and ergonomic concerns. Within warehousing operations, order picking stands out as one of the most crucial tasks [1]. It entails the process of collecting goods from a warehouse to complete customer orders [1]. The research results shows that majority, approximately 80%, of warehouses still heavily rely on manual order picking processes, with merely 5% being fully automated [2]. This brings up the question „What are the health effects on workers while they engage in order picking postures"?
In the research paper of Calzavara et al. [3], a comprehensive analysis of different rack layouts is conducted to improve both ergonomics and economic performance. Another research by Grosse et al. [4] delves into the study of ergonomic indicators for order picking tasks, investigating the differences between picking from full pallets on the floor, half pallets on the floor, and half pallets on the upper shelf. The main objective of this study [4] is to derive new mathematical models that prove useful in considering ergonomics during the design and subsequent management of an order picking warehouse.

Incorporating a content analysis of the literature, the paper by Calzavara et al. [5] analyses the human factors in order picking. Additionally, the research of Al Shehhi et al. [6] introduces anthropometric simulations of the goods-to-man order strategy using Siemens Jack software. The results [6] indicate significant flexion around the neck for both Jack and Eva, with the lower back and metabolic energy thresholds being approached. Similarly, in the research of Hussain et al. [7], simulation and method RULA are employed to analyze working postures, with certain postures modeled in CATIA V5 to assess risk levels. The conclusion drawn in [7] highlights how ergonomic interventions were successful in reducing the lifting index value, resulting in a safer limit. The study demonstrates that ergonomic interventions can effectively minimize risks associated with awkward working postures.

The research paper of Diefenbach and Glock [8], on the other hand, presents an ergonomic and economic optimization of layout and item assignment in a U-shaped order picking zone, aiming to minimize total walking distances or ergonomic strains during the picking process. In that sense, the paper of Gajšek et al. [9] concludes that companies should engage in open discussions with order pickers regarding the type of technology used, health issues in their working environment, preventive and curative care, and finally involve workers in decision-making.
In another study by Turk et al. [10], a simulation model for the lifting procedure is introduced, enabling the prediction of total time required for basic manual assembly tasks based on various load parameters, while taking into account workers' health. In addition, the objective of research paper by Ozdemir et al. [11] is to develop a model for designing assembly lines with consideration for ergonomic risks. This study also performs ergonomic risk analysis for assembly tasks using simulation software and incorporates the findings into the developed model.
The paper of author Gajšek et al. [12] proposes a solution to the storage assignment problem by developing a multi-objective model based on binary integer linear programming, which considers order picking time, energy expenditure, and health risk.

Authors Grabowik et al. [13] present a case study of a control station modeling, cogitating Poka-Yoke and ergonomic rules in Tecnomatix Jack Human Simulation, directly addressing industry needs. In addition, the research of Almazrouei et al. [14] validates the results obtained from human factors simulations by constructing a physical order

picking environment and comparing the responses of volunteers subjected to tasks like those simulated. The study concludes that the results from human factors simulations align with the volunteers' subjective experiences of discomfort and fatigue.
Furthermore, the paper by Kapou et al. [2] proposes an innovative method for designing picking area layouts and introduces a storage assignment strategy with a focus on ergonomics and workers' physical fatigue. The results demonstrate a remarkable 14.9% increase in productivity alongside a significant 31% decrease in the 'difficulty' index.

The review of available scientific literature on manual order picking in warehouses, provided a solid background regarding the main factors that have a strong influence on the central component of the system - the human order picker. Based on the gathered information, the variables for this research were chosen, as well as the ergonomic assessment tools applied for obtaining results from the virtual ergonomic simulation. The main objectives of this research, the used methodology, as well as the simulation results and discussions are elaborated in the following sections.

2 OBJECTIVES

This research aims to investigate the correlation between lifting containers with varying weight from different shelf positions and the ergonomics of the working task.
The main research questions that were addressed are:

(1) How strong is the influence of starting lifting position on the ergonomics of the lifting task?;
(2) Which is the optimal placement of containers, and which placement is the most critical?;
(3) What is the optimal container weight for different placement positions?; and
(4) What are the lower back compression forces on the worker while lifting containers from different positions and with different weight?

Addressing these questions was essential to understand the ergonomics of warehouse order picking processes with varying “lifting weight” and “lifting position” factors, identify challenges and risk factors and provide guidelines for further development of ergonomic warehouse solutions.

3 METHODOLOGY

This article is based on data extracted primarily from academic literature and publications. The keywords used in the search are: warehouse manual order picking, human factors in manual order picking, virtual ergonomic tools and ergonomic recommendations. Fig. 1 illustrates the steps taken to elaborate the main research questions.
For generating a simulated workspace to study the human factors in warehouse order picking, the Siemens Jack software was chosen as a virtual ergonomics tool that allows the creation and manipulation of 3D objects in 3D environments.

The warehouse shelf system and the containers were modeled separately according to dimensions of Medium-Duty Shelving System, which are available in the market and customized by the dimensions of the containers, and imported in Jack’s warehouse environment.
The default female mannequin – Jill, with a height of 163cm, belonging in the 50th height percentile, was used and adjusted in various static positions that helped to conduct ergonomic analysis of container-lifting tasks. The choice of mannequin was based on recommendations for selecting percentiles [15]. If a female worker with an average height has the strength and reach capability to perform the order picking tasks, it is very likely that the same tasks can be successfuly accomplished by other female workers of a larger height percentile, or other male workers.

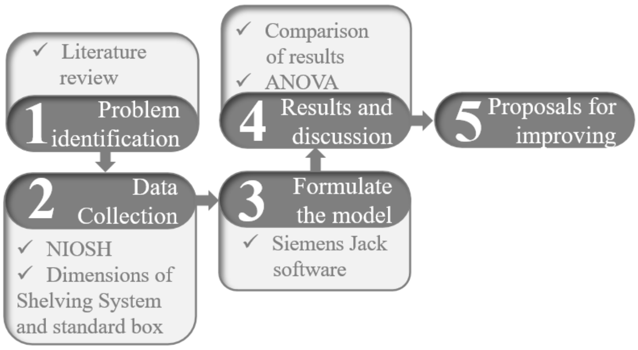

Fig. 1 *Methodology flowchart*

The experimental setup was a 2x3 design that consisted of two variables: “container (or box) weight” and “shelf position”. The dimensions of the containers/boxes were standard – 600x400x400mm, but their weight varied from 11.5kg to 23kg. The weight of 23kg was used as an extreme case, based on the National Institute of Occupational Safety and Health (NIOSH) Lifting Equation that uses a constant representing a maximum weight that can be lifted in ideal conditions (LC = 51 pounds, or about 23kg) [16].

The shelf positions were established as “bottom” – at a floor height of 130mm, “middle” – at a floor height of 1430mm and “top” – at a floor height of 1630mm. No higher shelves were considered since the analysis was focused on order picking from a worker on ground level, not relying on steps or stairs. The “container/box weight” (11.5kg & 23kg) and “shelf position” (“bottom”, “middle” & “top”) variables resulted in 6 different experimental conditions. The variables are illustrated in Fig.2 and the experimental design is elaborated in Table 1.

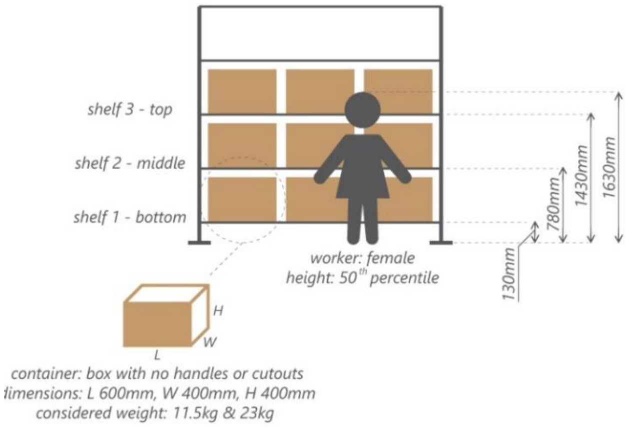

Fig. 2 *Simulation variables*

Table 1 Experimental design

CASE	BOX TYPE	SHELF POSITION		
	Weight	*Bottom*	*Middle*	*Top*
1	11.5kg	1	0	0
	11.5kg	0	1	0
	11.5kg	0	0	1
2	23kg	1	0	0
	23kg	0	1	0
	23kg	0	0	1

In the first simulation case, the mannequin was positioned to lift a container of 11.5kg, 3 times, each time from a different shelf height. The mannequin was manually placed in two different positions at each shelf – start lifting position (lift origin and end lifting position (lift destination). The procedure was the same for the second simulation case, when the container weight was 23kg. The start lifting positions were different while the end lifting position was the same in all cases. Then, the ergonomic analysis was done for each situation. The lifting positions for each shelf are given in Fig.3, Fig.4, Fig.5 and Fig.6.

Fig. 3 *Lift origin – bottom shelf*

Fig. 4 *Lift origin – middle shelf*

Fig. 5 *Lift origin – top shelf*

Fig. 6 *Lift destination*

To conduct the ergonomic analysis, Jack's Task Analysis Toolkit was used, or more precisely the NIOSH and Lower Back Analysis tools.

The NIOSH Lifting Analysis tool was chosen as most suitable to evaluate the lifting tasks, since it allows to examine whether a given weight or load, under given conditions and body positions, could be safely lifted by most workers in a given period of time [17].

The required input information for the use of this tool, aside from the lift origin and lift destination positions, were the average and maximum load weights, uninterrupted work time and recovery time. The NIOSH Lifting Analysis tool provided (for each of the 6 experimental conditions): the Recommended Weight Limit (RWL) – which is the maximum allowed weight to be lifted for the given characteristics; and a Lift Index (LI) – which is the relation between the given weight and the RWL and needs to be < 1.0 so that we can establish that the task is within the ergonomic recommendations [17]. The NIOSH Lifting Analysis tool helped to address research question no.2 and no.3.

The Lower Back Analysis tool, on the other hand, helped to determine the Low Back L4/L5 Compression Forces in each experimental condition, helping to determine whether the workplace tasks exceed the NIOSH Back Compression Limit value of 3400N and expose workers to a health-risk of low back injury [17]. The Lower Back Analysis tool helped to address research question no.1 and no.4.

The results from the analysis are elaborated in the next section.

4 RESULTS AND DISCUSSION

For a better comparison all results generated through the NIOSH Lifting Analysis tool and Lower Back Analysis tool were represented in a tabular form.

Results about the NIOSH LI and RWL are given in Table 2 and Table 3. The comparison of the results from NIOSH is illustrated on Figure 7. What is instantly apparent is that the LI in all conditions exceeds 1.0, meaning the loads of the containers exceed the recommended limit for the given conditions and some or most healthy workers would find the job physically stressful. The most critical positions are the bottom shelf and the top shelf. The middle shelf, which is within the comfortable reach zone, provides best access and avoidance of uncomfortable body positions (squatting or reaching over the head). This indicates that the heaviest loads should be positioned centrally. This conclusion is also based upon the NIOSH RWL for the given conditions – around 6kg for the bottom shelf, nearly 9kg for the middle shelf, and between 4kg and 5kg for the top shelf.

Table 2 Results from the NIOSH Lifting Analysis tool – Lift Index (LI)

NIOSH Lift Index (LI) < 1.0			
BOX TYPE	**SHELF POSITION**		
Weight	*Bottom*	*Middle*	*Top*
11.5kg	1.890	1.300	2.500
23kg	3.780	2.590	5.000

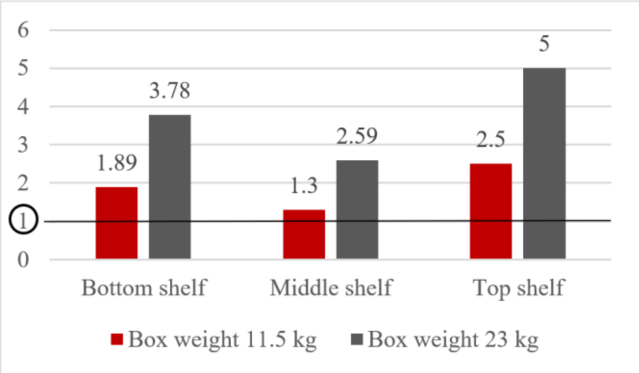

***Fig.** 7 Comparison of results from the NIOSH Lifting Analysis tool – Lift Index (LI)*

Table 3 Results from the NIOSH Lifting Analysis tool – Recommended Weight Limit (RWL)

NIOSH Recommended Weight Limit (RWL)			
BOX TYPE	**SHELF POSITION**		
Weight	*Bottom*	*Middle*	*Top*
11.5kg	6.090kg	8.860kg	4.600kg
23kg	6.090kg	8.860kg	4.600kg

Outcomes from The Lower Back Analysis tool, regarding the Low Back L4/L5 Compression Forces are given in Table 4 and Table 5. The comparison of the results from Lower Back Analysis is illustrated on Figure 8. A separate analysis was done for the lift origin and lift destination positions. What is evident is that the lower back compression force value exceeds the limit of 3400N only in the lift origin position for the bottom shelf when lifting the 23kg container. In all other cases, the force values are within a normal range.

However, we can see how they increase when increasing the load, or container weight, and they change between shelf positions. In this analysis, the bottom shelf has the worst results once more, but the compression forces reduce with the increase of shelf height. The force difference between bottom shelf and middle-top shelf is greater then the difference between middle shelf and top shelf.

Table 4 Results from the Lower Back Analysis tool – Lower Back L4/L5 Compression Forces (N) for lift origin positions

Lower Back L4/L5 Compression Forces (N) < 3400N			
BOX TYPE	**SHELF POSITION**		
Weight	*Bottom*	*Middle*	*Top*
11.5kg	2728	1333	1243
23kg	4232	2249	2024

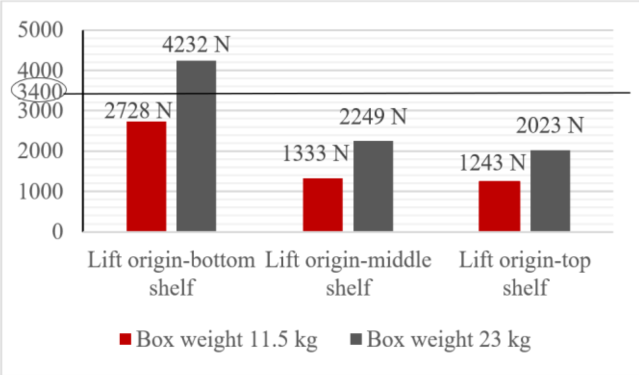

***Fig.** 8 Comparison of results - Lower Back Analysis tool*

Table 5 Results from the Lower Back Analysis tool – Lower Back L4/L5 Compression Forces (N) for lift destination positions (Destination positions are the same for all cases, so the values here are only dependent on the container weight)

Lower Back L4/L5 Compression Forces (N) < 3400N			
BOX TYPE	**SHELF POSITION**		
Weight	*Bottom*	*Middle*	*Top*
11.5kg	940	940	940
23kg	1490	1490	1490

Moreover, analysis of variance (ANOVA) two-factor without replication test was conducted to better determine if the difference between the compression force values for different container weights and shelf positions is significant. Results showed that there is a significant difference between the lifting ergonomics and lower back compression values between containers with different weights, $F = 23.11$, $p < 0.05$ ($p = 0.040$). There is also a significant difference between the lower back compression values between different shelf positions, $F = 28.361$, $p < 0.05$ ($p = 0.034$).

The obtained results provide a valuable base for withdrawing guidelines for enhancing the productivity and creating safer working environments. The main recommendations which can be pinpointed according to the analysed data are:

(1) The highest box/container should be positioned at up to 1800 mm from ground level, to be within reach for most workers, without the use of steps or stairs (based on the analysis with a 50th height percentile female worker with a height of 163cm).

(2) The heaviest boxes/containers should be placed at the position with optimal reach and grasp for the worker (780 – 1430mm).

(3) The recommended weight limit (RWL) of boxes/containers according to the NIOSH results should be taken into consideration: about 6 kg for

the bottom shelves, 9kg for the middle shelves and 5kg for the top shelves.

(4) If the boxes/containers have higher weights, the lifting frequency rates should be lowered and longer recover periods should be provided so that most healthy workers don't find the job physically stressful.

(5) Boxes/containers with handles or handhold cutouts should be used for easier grasping, lifting and carrying.

(6) The load should be positioned closer to the worker. The possible solution for better placement of the boxes/containers is to use shelves with an inclination of 30deg, which can help bring the load closer to the worker and enable a better position for a more comfortable and stable reach and grasp (Fig. 9).

What must be noted is that all the results are dependent on the provided characteristics of the simulations: mannequin of a female worker of the 50th height percentile (163cm height), shelves with specific heights (130mm bottom shelf, 780mm middle shelf and 1430mm top shelf), containers of 11.5kg and 23kg with no handles or cutouts, lifting frequency rate of 3lifts/min, uninterrupted work time of 2hrs, and recovery time of 0.2hrs.

***Fig. 9** Suggestion improvement – inclined shelfs (30deg) for easier reach and grasp in challenging positions*

5 CONCLUSION

The research presented in this paper is helpful in identifying the ergonomic weaknesses in manual order picking of containers in warehouses and addressing them through two different positions at each shelf (lift origin and lift destination) simulated in a workspace created with the Siemens Jack software. The weight of containers that were used in the simulation were based on NIOSH weight recommendations. For the purpose of carrying out the ergonomic analysis, Jack's Task Analysis Toolkit was used, more precisely the NIOSH and Lower Back Analysis tools. The results of the ergonomic analysis pointed out the most critical lifting position, lower back compression forces on the worker during lifting containers, and optimal container weight for different placement positions. The obtained results helped to address the initial reseacrch questions, and determine possibilities for further research.

Firstly, the simulations showed a significant influence of the starting lifting position (or lift origin) on the ergonomics of the lifting task. The LI and L4/L5 compression forces were highest where the lift origin involved a bending and reaching position, and where there was a larger travel distance of the loads that were lifted or lowered (larger difference between the origin and destination position).

Secondly, it was evident that the middle shelf, specifically accommodating an 11.5kg container, was the optimal location, offering superior accessibility and preventing uncomfortable body postures (such as squatting or overhead reaching). The simulations confirmed that placing containers for MMH within the power zone of the workers reduces the risk conditions and provides a better fit between the working task and worker capability, enabling more ergonomic lift-lower movements.

Thirdly, the NIOSH RWL for the provided simulation conditions showed that the most suitable container weight ranges from 6kg for the bottom shelf, nearly 9kg for the middle shelf and between 4kg and 5kg for the top shelf. This shows once more that the most critical positions are the bottom and top shelf, and therefore the heaviest containers should be placed in the middle, within the most comfortable reach zones, allowing a reduction of the back stress. It is important to note that the NIOSH RWL is calculated through several task variables and additional variables [16] which are an indicator of the most crucial factors that need to be considered to properly design the working task. Generally, the containers should be placed at a closer relative distance to the body, the vertical moving distance of the container while lifting should be reduced, the origin and destination positions should be planned properly to reduce the body asymmetry and body twisting, the containers should provide optimal grip through adequate handles, and the frequency of the lifting task should be determined according to the container weights.

Finally, regarding the lower back compression forces, the results showed they exceed the 3400N threshold solely in the initial lifting position for the 23kg container on the bottom shelf. For all other scenarios, the force values remained well within the normal range. However, the analysis of variance helped to answer the fourth research question and confirmed that there is a significant correlation between the lower back compression forces and the container weights, as well as the lower back compression forces and the shelf positions.

In summary, this research highlights the most important factors related with efficient and safe MMH within warehouse environments, pinpointing strategies for improving the ergonomics. Further research in this area needs to involve advanced motion simulations, using the Task Simulation Builder (TSB), and increased number of variables – mannequins of different gender and different height percentiles, shelves with different inclination angles, containers with different weights and coupling (handles), and different lift origin-destination solutions. Increased number of variables will result in a more complex experimental setup, but the TSB ergonomic reports and time reports will provide a better understanding of the needed warehouse shelf design, container design and lifting techniques for MMH that will result in a workspace where the risk of injury and discomfort is significantly reduced and the workers' efficiency is increased.

We hope that this research raises the importance of applying user-centric design principles in warehouses to ensure the well-being of workers and exploring various strategies for improving the ergonomics of MMH task which can result in greater operational productivity, and overall organizational success.

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AN ANALYSIS OF PERFORMANCE-BASED LOGISTICS ADVANTAGES USING A POLYTOPIC FUZZY SUBJECTIVE WEIGHTING APPROACH: A CASE STUDY OF MANUFACTURING FIRMS IN ORDU PROVINCE

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Abstract

Effective supply chain management and business sustainability are getting more expensive and difficult in terms of logistical processes. Performance-based logistics solutions are becoming crucial for businesses in this framework. This study explored the degrees of performance-based logistics application in manufacturing firms, with the goal of determining the factors influencing the advantages of performance-based logistics and prioritizing the identified components. To weight the criteria determined for this aim, a subjective weighting approach based on Polytopic Fuzzy Sets was employed. It has been found that the most important criterion is " Providing more effective management " as a result of the implementation of this weighting approach based on the polytopic fuzzy weighted aggregation operator.

Keywords: *Performance, Performance-Based Logistics, Polytopic Fuzzy Sets, Subjective Weighting, Multi-criteria Decision Analysis.*

1. INTRODUCTION

With the phenomenon of globalization, various events and changes occurred in almost all technological, economic, and social processes in the last century. These changes and developments associated with elements of supply chain management and logistics performance such as cost, quality, flexibility, efficiency, etc. have made these issues important for every industry and it has become necessary to ensure the sustainability of these concepts by offering a solution offered competitively. Advantage. One of the important indicators for obtaining a competitive advantage, especially for manufacturing companies, undoubtedly depends on the success of logistics efficiency factors [1]. Among these approaches, the concept of performance-based logistics has emerged, a sustainable and more cost-effective approach that emphasizes system availability, includes performance targets specified in contracts, and can respond more quickly to customer requirements [2].

Performance-based logistics is expressed as an integrated supply and sustainability strategy based on long-term relationships with organic or outsourced support providers and an appropriate incentive structure to increase the capabilities of the systems and combat readiness levels in a way that supports the end user's objectives [3]. In another definition, the concept is; ensures sustainability by building long-term relationships between customers, support providers, and supplier base, creates a motivation mechanism for performance development, and significantly increases the level of operational readiness of systems [4].

When considered in this context, performance-based logistics emerges as a logistics support system that will enable the manufacturer to offer an operation and maintenance opportunity at the required level of readiness, in line with the logic of outsourcing, thanks to a comprehensive contract. Although it may seem very costly at first, with performance-based logistics, the institution will actually get rid of the above-mentioned costs and will also achieve the desired availability rate [5].

In particular, programs that employ performance-based logistics practices save billions of dollars compared to traditional approaches, while increasing system availability by 40 percent and reducing logistics response times by 70 percent. The goal of these practices and strategies is to create a contract structure that controls costs, encourages investments to increase product reliability, maintains profit margins, and reduces government costs [6].

Furthermore, when entrepreneurs and the government form long-term, profitable partnerships in performance-based logistics practices, the entrepreneur believes that he will maximize his profits by using all of his skills to achieve the results desired by the government. According to him, contractors will ensure project optimization by designing efficient, high-performance, reliable, and user-friendly systems. On the other hand, he argues that the most important issue in performance-based logistics is to reward high performance and punish poor performance [7].

According to Bayram (2010), a performance-based logistics approach is becoming increasingly common in global procurement because it offers benefits to both the employer and the contractor. He also adds that, on the one hand, the customer only pays for results and, on the other hand, entrepreneurs have the necessary freedom to further develop their knowledge and skills on a specific topic, and financial incentives are used for this. On the other hand, because traditional purchasing approaches focus on internal logistics processes and often do not directly address users' needs, this approach has the negative impact of limiting innovation and process improvements. Additionally, the traditional approach encourages holding more stocks. Due to these factors, it is difficult to provide cost-effective integrated logistics support using traditional methods [8].

From this point of view, performance-based logistics approaches are beneficial for businesses and beneficiaries.

It affects vitally important issues such as cost, efficiency, competition, performance, effectiveness, and customer satisfaction. Therefore, performance-based logistics application advantages are seen as critical components. Because transforming supply chain management into an agile structure affects not only the production processes but also the entire process up to the end consumer, performance-based logistics practices are key issues that need to be carefully considered.

Based on all these issues, the study aims to identify the benefits of performance-based logistics applications in manufacturing companies with corporate identity in Ordu Province and classify them using multi-criteria decision analysis methods. The study also highlights the literature review on the applications and concepts of performance-based logistics, which constitutes the research method. Multi-subject fuzzy sets (PTFS) explanations and the application of the method for Ordu Province were examined. The final part of the article presents information about the results and future research.

2. LITERATURE REVIEW

Some studies in the national and international literature on performance-based logistics are given below;

Randall et al. (2010) conceptually examined the development of a performance-based logistics theory using service-dominant logic and drew lessons for the future [6].

Mirzahosseinan and Paplani (2011) developed an inventory model of a system of repairable parts operated under a performance-based logistics contract. As a result, it was determined that component safety and repair times needed to be improved [9].

Jin and Wang (2012) analyzed performance-based logistics planning and contracting with a genetic algorithm in cases where the system usage rate is uncertain [10].

Mirzahosseinian and Piplani (2013) examined the effect of the system quantity on the support provider service level within the scope of a performance-based logistics contract using the parametric analysis method [11].

Kashani Pour et al. (2014). investigated determining the ideal payment amount and period for the public sector using a stochastic model in a performance-based logistics application framework [12].

Selviaridis and Norman (2015) examined the challenges of performance-based logistics contracts for advanced logistics systems. In this context, the main challenges have emerged in creating automation systems capable of monitoring performance, setting appropriate incentive models, and managing processes and resources through a proactive approach on the part of the service provider [13].

Davis et al. (2016) examined the essential characteristics of successful performance-oriented logistics teams. In addition, they identified the important elements that make up a successful agreement [14].

Kim et al. (2017) investigated the benefits and drawbacks of classical support strategies and performance-based logistics strategies are revealed and compared using the game theory method. As a result, they concluded that performance-based logistics practices are much more effective [15].

Sharifi and Kwon (2018) examined the cost uncertainty of performance-based contract design [16].

Ağdaş et al. (2019) implemented a dynamic performance evaluation within the scope of performance-based logistics in the defense industry [17].

Listoy et al. (2020) expressed it as identifying the barriers and facilitators to performance-based logistics and determining the output expectations of different stakeholders [18].

Malyemez and Baykoç (2021) proposed a new multi-objective optimization model for the repair level of the analysis problem in performance-based logistics [19].

Yoon et al. (2022) examined an effective, performance-based logistics management program in the fourth industrial revolution [20].

Polat et al. (2023) created a competitiveness-based logistics performance index through empirical analysis in Organization for Economic Cooperation and Development countries [21].

A detailed literature review presents the applications of performance-based logistics and its advantages. As a result of this, very little research has been found on these topics. In this phase, the study makes use of the literature. It is believed that this will contribute to this**.**

3. METHODOLOGY

To handle different difficult decision-making issues, Bet et al. (2022) presented the notion of polytopic fuzzy sets (PTFSs) as a generalization of spherical fuzzy sets (SFSs), picture fuzzy sets (PFSs), and q-rung orthopair fuzzy sets (q-ROFSs). Beg et al. (2022) claimed that the PTFS theory gives appropriate approaches for dealing with imprecisions and uncertainties in input data required to solve decision problems where the SFS, PFS, and q-ROFS theories are not applicable. For this reason, PTFS was used to address the decision-making problem in this study [22].

Let X be a universe of discourse, then a PTFS H of X can be written as $H = \{\langle x, \alpha_H(x), \eta_H(x), \beta_H(x) \rangle : x \epsilon X\}$, where $0 \leq \alpha_H(x)^q + \eta_H(x)^q + \beta_H(x)^q \leq 1$. Also, $\alpha_H : X \to [0,1]$, $\eta_H : X \to [0,1]$, $\beta_H : X \to [0,1]$ are the positive membership degree, neutral membership degree, and negative membership degree of $x \epsilon X$ to PTFS H, respectively. In this study, $\langle \alpha, \eta, \beta \rangle$ is called PTF number (PTFN) for the sake of simplicity. The operators for PTFNs are given in Eq.s (1)-(5), where $h = \langle \alpha, \eta, \beta \rangle$, $h_1 = \langle \alpha_1, \eta_1, \beta_1 \rangle$, $h_2 = \langle \alpha_2, \eta_2, \beta_2 \rangle$ are three PTFNs [22].

$$h_1 \otimes h_2 = \langle \alpha_1 \alpha_2, \eta_1 \eta_2, \left(\beta_1^q + \beta_2^q - \beta_1^q \beta_2^q\right)^{1/q} \rangle, \quad (1)$$

$$h_1 \oplus h_2 = \langle \left(\alpha_1^q + \alpha_2^q - \alpha_1^q \alpha_2^q\right)^{1/q}, \eta_1 \eta_2, \beta_1 \beta_2 \rangle, \quad (2)$$

$$h^c = \langle \beta, \eta, \alpha \rangle, \quad (3)$$

$$h^\lambda = \langle \alpha^\lambda, \eta^\lambda, \left(1 - (1 - \beta^q)^\lambda\right)^{1/q} \rangle, \quad (4)$$

$$h\lambda = \langle \left(1 - (1 - \alpha^q)^\lambda\right)^{1/q}, \eta^\lambda, \beta^\lambda \rangle, \quad (5)$$

The score function ($\mathcal{S}(h)$) and accuracy function ($\mathcal{A}(h)$) are computed as follows [22].

$$\mathcal{S}(h) = \frac{1+\alpha^q+\eta^q-\beta^q}{3}, \quad (6)$$

$$\mathcal{A}(h) = \frac{1+\max(\alpha^q,\eta^q)-\beta^q}{2} \quad (7)$$

PTF weighted aggregation operator (PTFWA) is computed using Eq. (8), where h_i for $i = 1, \dots, m$ are PTFNs [22].

$$PTFWA(h_1,\dots,h_m) = \langle \left(\left(1 - \prod_{i=1}^{m} \left(1-\alpha_i^q\right)^{k_i} \right)^{1/q} \right), \prod_{i=1}^{m} \eta_i^{k_i}, \prod_{i=1}^{m} \beta_i^{k_i} \rangle \quad (8)$$

Also, k denotes the weight vector, where $k = 1, \dots, r$ in Eq. (8).

The PTF subjective weighting approach's implementation steps are presented below.

Step 1. The decision-making problem and its components are determined. Thus, $C_1, \dots, C_n$ represents criteria, and $U_1, \dots, U_r$ depicts decision-makers or experts.

Step 2. Experts assess the importance of criteria based on the linguistic expressions presented in Table 1 [23].

Table 1. Linguistic Expressions for Evaluation of Criteria

		Related PTFNs		
Linguistic Expressions	Codes	α	η	β
Extremely Important	EI	0.9	0.1	0.1
Very High Important	VHI	0.8	0.2	0.2
High Important	HI	0.7	0.3	0.3
Slightly More Important	SMI	0.6	0.4	0.4
Medium Important	MI	0.5	0.5	0.5
Slight Low Important	SLI	0.4	0.4	0.6
Low Important	LI	0.3	0.3	0.7
Very Low Important	VLI	0.2	0.2	0.8
Extremely Unimportant	EU	0.1	0.1	0.9

The importance of each criterion is shown with $\iota_{jk} = \langle \alpha_{jk}, \eta_{jk}, \beta_{jk} \rangle$ once linguistic evaluations are obtained.

Step 2. The expert weights (ξ_k) are calculated. We assign equal weight to experts in our study.

Step 3. Eq. (9) is used to determine the integrated PTF importance values, where $k = 1, \dots, r$ and $j = 1, \dots, n$.

$$\iota_j = \langle \left(\left(1 - \prod_{k=1}^{r} \left(1-\alpha_{jk}^q\right)^{\xi_k} \right)^{1/q} \right), \prod_{k=1}^{r} \eta_{jk}^{\xi_k}, \prod_{k=1}^{r} \beta_{jk}^{\xi_k} \rangle, \quad (9)$$

Step 4. Eq. (10) is used to compute the weight coefficient of each criterion, where $\mathcal{S}(\iota_j)$ is the score function of ι_j.

$$w_j = \frac{\mathcal{S}(\iota_j)}{\sum_{j=1}^{n} \mathcal{S}(\iota_j)}$$

As a consequence, the weights of the criteria are determined, where $\sum_{j=1}^{n} w_j = 1$, and $0 \le w_j \le 1$.

4. FINDINGS

(8)

Three logistics managers (E1, E2, and E3) rated the importance of the criteria. These evaluations are shown in Table 2.

Table 2. The Linguistic Importance Evaluations of Criteria Provided by Experts.

Criteria	Source	Notations	E1	E2	E3
Improving performance and quality while keeping costs low	[24] and [25].	C1	EI	VHI	VHI
Concentrating on essential tasks and improving core capabilities	[28] and [1].	C2	EI	VHI	EI
Following technological innovations	[26].	C3	VHI	HI	EI
Increasing flexibility and resource transfer	[26] and [27].	C4	HI	SMI	VHI
Using outsourcing qualifications	[1].	C5	VHI	SLI	HI
Providing more effective management	[26] and [27].	C6	EI	EI	EI
Extending the system life cycle and increasing system readiness	[24].	C7	VHI	VHI	VHI
Preventing systems from early modernization, out-of-stock, and renovation	[24] and [1].	C8	VLI	HI	VHI
Reducing problems in the legislation	[8].	C9	VHI	MI	HI
System life cycle cost reduction through labor and training savings	[8].	C10	EU	VLI	HI

The calculations outlined in Eq.s (9)–(10) were carried out. Therefore, the weighting results are shown in Table 3.

(9)

Table 3. The weighting results.

	C1	C2	C3	C4	C5
Wj	0.112	0.117	0.109	0.096	0.092
Rank	3	2	4	6	8
	C6	C7	C8	C9	C10
Wj	0,121	0,106	0,090	0,094	0,065
Rank	1	5	9	7	10

,

The most important criterion is C6 (Providing more effective management) as shown in Table 3. Also, the importance ranking order of criteria is determined as C6≻ C2≻ C1≻ C3≻ C7≻ C4≻ C9≻ C5≻ C8≻ C10.

5. CONCLUSION

Today, one way for businesses to maintain their competitiveness and flexibility is through the effectiveness of logistics performance factors. The success of performance-based logistics applications in terms of increasing the production level of businesses to the desired level and ensuring customer satisfaction is one of the issues that should be emphasized. In this way, operational efficiency and cost savings can be achieved.

However, if performance-based logistics applications are not at the desired level and coordination, they may cause various risks and problems. Therefore, this situation reflects negatively on businesses and can cause a wide range of losses to businesses in terms of effectiveness, efficiency, competitiveness, and cost advantage.

In this context, the study identified and examined the benefits of performance-based logistics applications in corporate identity production companies in Ordu Province. According to the research carried out, the most important factors regarding the benefits of using performance-based logistics applications are: “Providing more effective management”, “Concentrating on the essential task and improving core capabilities” and “Improving performance and quality while keeping costs low”, respectively.

In other words, effective management practices represent important issues that influence the success of performance-based logistics applications. Therefore, effective management systems and practices can influence the performance of the supply chain, thereby contributing to the level of efficiency that can be achieved in both the production processes and the processes that promote production and service levels. With regard to the development of efficiency and cost advantages, efficiency-based logistics applications are seen as central topics that manufacturing companies cannot do without. At the same time, it can be argued that one way to increase the efficiency and competitiveness of manufacturing companies is the success of performance-based logistics applications.

At this point, the study can be considered as a guide in filling an important gap in revealing the success and advantages of the performance-based logistics applications listed above. In the future, the subject can be studied using different multi-criteria decision analysis methodologies. It can also be expanded by comparing the outcomes of different methods. Multiple methods, for example, can be defined under other fuzzy sets, and their results can be compared and discussed.

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AN APPLICATION FOR THE PROBLEMS FACED BY BUSINESSES USING E-LOGISTICS: A CASE OF GIRESUN PROVINCE

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Abstract

Manufacturing businesses are continually competing as a result of globalization, both on a sectoral and customer demand basis. Thus, advancements in e-commerce and technology have pushed e-logistics applications to the forefront, necessitating a focus on them. In this context, the problems that firms encounter while implementing e-logistics become important, and one of the components that must be carefully evaluated. Factors influencing the problems encountered by firms employing e-logistics have been identified, and the identified factors are being prioritized. In order to weight the criteria, a subjective weighting approach based on Polytopic Fuzzy Sets was employed. According to the findings of the examination, " Lack of skill to manage digital technologies to support the system " is the most important criterion in the problems encountered by firms adopting e-logistics.

Keywords: *Logistics, E-logistics, Problems Encountered by Firms Using E-Logistics, Polytopic Fuzzy Sets, Subjective Weighting, Multi-criteria Decision Analysis.*

1 INTRODUCTION

Logistics, which forms the basis for activities and transactions between suppliers, manufacturers, distributors, and customers within the supply chain, is an important business area for both manufacturing and service companies. Today, every company wants to improve its competitiveness and increase the efficiency of its operations. Companies therefore generally have a flexible structure. [1]. With the increase in e-commerce due to technological development, logistics activities have increased significantly. With the advent of e-commerce, logistics companies have started using electronic logistics in their operations. By using electronic logistics, companies can ensure that the processing of their products, from production to point of consumption, occurs quickly and accurately [2].

Conceptually, e-logistics refers to the entire logistical process that ensures customer satisfaction in online purchases and e-commerce transactions. In addition to these e-logistics transactions; This means that processes such as inventory management, storage, transport, and distribution are better adapted to the new requirements of the digital age. [3]. In another definition, it refers to providing electronically based services at a competitive cost by integrating services such as storage, transportation, and stock management within the value chain [4]. Beyond the various definitions, e-logistics in the most general sense is the implementation of a logistics process in an electronic environment. In a system that offers companies significant advantages in product delivery, shipping planning, scheduling, routing, and delivery processes, ensuring an optimal level of speed and adaptability in the delivery of after-sales services, customers can monitor the entire process from the very beginning of the Internet and thus positively influence the relationships between customers and companies [5]. The three major goals of electronic logistics are to minimize company expenses, reduce shipment times, and meet consumer expectations. This goal has four major components: strategy planning, partner formation, inventory management, and information management. All these four main aspects are interrelated and help ensure deliveries of products at the right time and minimum cost. On the other hand, they are seen as the main supporters of a successful e-logistics system [4].

In addition, advances in e-logistics data management and increasingly complex planning and scheduling systems improve the delivery of goods and services at lower costs through the development of methods for supply chain management [6].

However, e-logistics applications that aim to accelerate logistical processes and implement corresponding systems do not always bring advantages for companies. This creates an unfavorable situation in some respects and companies can sometimes run into problems [7]. For example, the lack of ability to manage the digital technologies that will support the system is expressed as not being ready to develop these skills and combat difficulties [8].

In addition, other questions related to e-logistics applications; are manifested in economic and educational problems, lack of infrastructure, channel conflicts, lack of sufficient software and hardware in the company, delivery delays, processing problems or delays in returning products, problems in the program used, security problems of information, etc. geographical obstacles [9].

Despite all these disadvantages, companies can overcome these difficulties by managing their e-logistics systems correctly and strengthening their technological infrastructure [5].

Even if the problems and inconveniences encountered are not global, it is equally important that the economic and logistic infrastructures of the recipient countries are compatible with the information and technology systems. Although the disadvantages and problems encountered may be the reason why companies decide against electronic logistics, it is believed that the opportunity to take advantage of the positive advantages of the new world order and technology is important to gain an advantage to obtain on the market.

Framework conditions enable companies to achieve long-term profits [10].

From this point of view, the problems faced by companies using e-logistics touch on extremely important issues such as costs, efficiency, competitiveness, effectiveness, and customer satisfaction of companies and beneficiaries. The problems faced by companies using electronic logistics are therefore considered critical elements. Since the flexible design of customer satisfaction is not just about service processes, but about the entire process up to the end consumer, the problems of companies that use e-logistics are central issues that need to be carefully considered.

Based on all these issues, the study aims to identify the problems encountered by logistics enterprises with corporate identity in Giresun using e-logistics and to rank them using multi-criteria decision analysis methods.

In the following sections of the study, the problems and concepts encountered by businesses using e-logistics will be discussed. By focusing on the relevant literature review, explanations about Polytopic Fuzzy Sets (PTFSs), which constitute the method of the study, and the application of the method for the province of Giresun were examined. In the last part of the study, results and information about future studies are presented.

2 LITERATURE REVIEW

Some studies in the national and international literature on e-logistics are given below;

Ekici and Yıldırım (2010) provided information about the effects of e-commerce on the performance of logistics businesses [11].

Rao et al. (2011) examined the impact of e-logistics service quality on customer purchasing satisfaction and retention [12].

Hernández et al. (2012) examined the critical success factors model for the implementation of the e-logistics system [13].

Wang, et al. (2013) examined RFID Based Data Mining for e-logistics. [14].

Tekin (2014) examined electronic logistics applications in e-logistics and drug distribution [15].

Skitsko (2015) examined the relationship between previous aspects of evaluation and the company's e-logistics development [16].

Kim et al. (2016) conducted a structured review of the trend of e-logistics research in Korean journals [17].

Türkmen and Sarıcan (2017) conducted a study to determine the critical factors in e-logistics in logistics companies in Türkiye. Additionally, they presented the data obtained from factor analysis for the models to be created in subsequent studies [18].

Tekin et al. (2017) emphasized that the sector that uses information communication technology and internet infrastructure and manages this technology provides many advantages such as time, speed, and cost for educational activities with this infrastructure [19].

Karayün and Uca (2018). evaluated the impact of online customer portals on freight operations within the scope of e-logistics within the framework of case analysis [20].

Kanagavalli and Azeez (2019). identified the advantages and challenges of logistics and e-logistics management [21].

Tetik and Eroğlu (2020) researched to examine the critical factors, advantages, and disadvantages of the e-logistics system [5].

Jain et al. (2021) examined electronic logistics service quality and repurchase intention in e-retailing within the framework of the catalytic role of shopping satisfaction, payment options, gender, and return experience [22].

Türkmen and Sarıcan (2022) investigated the effects of e-service quality on shopping satisfaction, payment options, and repurchase intention in e-logistics applications [23].

Ta et al. (2023) examined crowdsourced delivery and customer evaluations of e-logistics service quality [24].

A detailed literature review presents the applications of e-logistics and its problems, and very little research has been found on these topics. In this phase, the study makes use of the literature. It is believed that this will contribute to this.

3 METHODOLOGY

Bet et al. (2022) proposed the concept of polytopic fuzzy sets (PTFSs) as a generalization of spherical fuzzy sets (SFSs), picture fuzzy sets (PFSs), and q-rung orthopair fuzzy sets (q-ROFSs) to address various challenging decision problems. It was noted that the PTFS theory provides suitable tools for dealing with imprecisions and uncertainties in input data required for decision problems where the SFS, PFS, and q-ROFS theories are inapplicable [25]. In this context, we employed PTFS to solve the decision problem in this study.

Assume that X is a universe of discourse, then a PTFS G of X can be written as $G = \{\langle x, \alpha_G(x), \eta_G(x), \beta_G(x) \rangle : x \epsilon X\}$. Also, $\alpha_G: X \to [0,1]$ is the positive membership degree, $\eta_G: X \to [0,1]$ is the neutral membership degree, and $\beta_G: X \to [0,1]$ is the negative membership degree of $x \epsilon X$ to PTFS G. The condition $0 \leq \alpha_G(x)^q + \eta_G(x)^q + \beta_G(x)^q \leq 1$ should be satisfied [25].

For the sake of simplicity, $\langle \alpha, \eta, \beta \rangle$ is called PTF number (PTFN). The operators, score function ($\mathcal{S}(g)$), accuracy function ($\mathcal{A}(g)$), and PTF weighted aggregation operator (PTFWA) are given below, where $g = \langle \alpha, \eta, \beta \rangle$, $g_1 = \langle \alpha_1, \eta_1, \beta_1 \rangle$, $g_2 = \langle \alpha_2, \eta_2, \beta_2 \rangle$ are three PTFNs

$$g_1 \oplus g_2 = \langle \left(\alpha_1^q + \alpha_2^q - \alpha_1^q \alpha_2^q\right)^{1/q}, \eta_1 \eta_2, \beta_1 \beta_2 \rangle \quad (1)$$

$$g_1 \otimes g_2 = \langle \alpha_1 \alpha_2, \eta_1 \eta_2, \left(\beta_1^q + \beta_2^q - \beta_1^q \beta_2^q\right)^{1/q} \rangle \quad (2)$$

$$g^\lambda = \langle \alpha^\lambda, \eta^\lambda, \left(1 - (1 - \beta^q)^\lambda\right)^{1/q} \rangle \quad (3)$$

$$g\lambda = \langle \left(1 - (1 - \alpha^q)^\lambda\right)^{1/q}, \eta^\lambda, \beta^\lambda \rangle \quad (4)$$

$$g^c = \langle \beta, \eta, \alpha \rangle \quad (5)$$

$$\mathcal{S}(g) = \frac{1 + \alpha^q + \eta^q - \beta^q}{3} \quad (6)$$

$$\mathcal{A}(g) = \frac{1 + \max(\alpha^q, \eta^q) - \beta^q}{2} \quad (7)$$

$$PTFWA(g_1,\dots,g_n) = \langle \left(\left(1-\prod_{i=1}^{m}\left(1-\alpha_i^q\right)^{k_i}\right)^{1/q}\right), \prod_{i=1}^{m}\eta_i^{k_i}, \prod_{i=1}^{m}\beta_i^{k_i}\rangle$$

(8)

In Eq. (8), g_i for $i = 1,\dots,m$ are PTFNs. Also, k denotes the weight vector, where $k = 1,\dots,r$.

The implementation steps of the PTF subjective weighting approach are detailed below.

Step 1. The decision problem is defined. Thus, $C_1,\dots,C_n$ depicts criteria, and $U_1,\dots,U_r$ denotes experts or decision-makers.

Step 2. Experts evaluate the importance level of criteria according to linguistic terms listed in Table 1 [26].

Table 1. Linguistic terms for evaluation of criteria.

		Corresponding PTFNs		
Terms	Notations	Positive Membership	Neutral Membership	Negative Membership
Extremely Important	EI	0.9	0.1	0.1
Very High Important	VHI	0.8	0.2	0.2
High Important	HI	0.7	0.3	0.3
Slightly More Important	SMI	0.6	0.4	0.4
Medium Important	MI	0.5	0.5	0.5
Slight Low Important	SLI	0.4	0.4	0.6
Low Important	LI	0.3	0.3	0.7
Very Low Important	VLI	0.2	0.2	0.8
Extremely Unimportant	EU	0.1	0.1	0.9

After obtaining linguistic evaluations, the importance of each criterion is shown with $\iota_{jk} = \langle \alpha_{jk}, \eta_{jk}, \beta_{jk} \rangle$.

Step 2. The weights of experts (λ_k) are determined. In this study, we give equal weights to experts.

Step 3. The integrated PTF importance values are computed using Eq. (9), where $k = 1,\dots,r$ and $j = 1,\dots,n$.

$$\iota_j = \langle \left(\left(1-\prod_{k=1}^{r}\left(1-\alpha_{jk}^q\right)^{\lambda_k}\right)^{1/q}\right), \prod_{k=1}^{r}\eta_{jk}^{\lambda_k}, \prod_{k=1}^{r}\beta_{jk}^{\lambda_k}\rangle$$

(9)

Step 4. The weight coefficient of each criterion is calculated via Eq. (10), where $\mathcal{S}(\iota_j)$ denotes the score function of ι_j.

$$w_j = \frac{\mathcal{S}(\iota_j)}{\sum_{j=1}^{n}\mathcal{S}(\iota_j)} \qquad (10)$$

As a result, criteria weights are determined, where $\sum_{j=1}^{n} w_j = 1$, and $0 \le w_j \le 1$.

4 FINDINGS

(8)

Three logistics managers (E1, E2, and E3) evaluated the importance levels of the criteria. Table 2 shows these assessments.

Table 2. Experts' linguistic evaluations related to the criteria.

Criteria	Source	Notations	E1	E2	E3
Lack of skill to manage digital technologies to support the system	[7] and [20].	C1	VHI	HI	EI
Infrastructure-related additional costs	[8] and [1].	C2	HI	HI	VHI
Need for Qualified Personnel	[9] and [17.	C3	VHI	HI	VHI
Need for Training and Seminars	[9] and [21].	C4	HI	HI	HI
Uncertain Legal Arrangements for E-Logistics Applications	[7] and [8].	C5	MI	MI	MI
High Cost of Software and Application Program Updates and Maintenance	[11] and [17].	C6	HI	HI	VHI
Uncertainty in Selecting the Proper System to Be Used	[9].	C7	MI	SLI	HI
Organizational Resistance to E-Logistics Applications and Channel Conflicts	[8].	C8	MI	SLI	SLI
Security, Safety, and Privacy Issues	[7].	C9	MI	HI	HI

The computations defined in Eq.s (9)-(10) were followed. Then, the weighting results given in Table 3 were obtained.

Table 3. The weighting results.

(9)

	C1	C2	C3	C4	C5
W_j	0.133	120	0,125	0.115	0,096
Rank	**1**	**3**	**2**	**5**	**8**
	C6	**C7**	**C8**	**C9**	
W_j	0,120	0,099	0,084	0,109	
Rank	**3**	**7**	**9**	**6**	

(10)

As seen in Table 3, the most important criterion is "lack of skill to manage digital technologies to support the system" (C1). Also, the importance ranking order of criteria is obtained as C1≻C3≻C2~C6≻C4≻C9≻C7≻C5≻C8.

5 CONCLUSION

Technological developments in recent years have forced companies to change towards a faster and more flexible structure. The constantly evolving information and communication infrastructures have pushed companies to use e-logistics as a means to maintain their competitiveness and flexibility. The use of electronic logistics is one of the issues that needs to be paid attention to when it comes to raising the service level of companies to the desired level and ensuring customer satisfaction. In this way, companies can save and save money.

However, if e-logistics applications are not at the desired level and coordination, they may cause various risks and problems. Therefore, this situation reflects negatively on businesses and can cause a variety of losses to businesses in terms of effectiveness, efficiency, competitiveness, and customer satisfaction.

In this context, in the study, the problems in e-logistics applications in logistics enterprises with corporate identity in Giresun were identified and investigated. According to the results of the study, the most important factors related to e-logistics problems were determined to be "Lack of skill to manage digital technologies to support the system", "Need for Qualified Personnel" and "Infrastructure-related additional costs", respectively.

In other words, the most important factor in the success of e-logistics applications is expected to be the lack of skills in using the digital technologies that will support the system. This is because companies have not yet adequately adapted to digitalization and electronic applications. In addition, the lack of personnel with the desired qualifications and knowledge poses significant problems in electronic logistics applications. Additionally, businesses that cannot ensure cost effectiveness fail in the use of e-logistics, thus having a negative impact on business performance and efficiency. Related problems can be overcome by training, personnel empowerment, and awareness-raising, and by combining business strategies with realistic cost elements.

In addition, it is important that employees of all units understand that e-logistics applications are crucial in achieving cost advantages for companies. It can be concluded that one of the ways to increase the efficiency and competitiveness of companies lies in the effective application of e-logistics.

At this point, the study can be considered as a guide in filling an important gap in revealing the problems of e-logistics applications above.

Again, research may be evaluated in the future using different multi-criteria decision analysis methods or other parametric or non-parametric methods. This can also be improved by adding different fuzzy sets and the results can be compared and discussed.

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RESHORING IN ORDER OF MINIMIZING SUPPLY RISK

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Abstract

Reshoring is becoming some kind of a trend in terms of global supply chains structuring. Scientifics get impression that this change in the supply chains structure has become particularly relevant with intensify of factors that initiated disruptions and interruptions at the supply chain level. Efforts by managers to reduce exposure to factors that lead to disruptions in the chain have led to the return of production of components and/or parts to the home or nearby countries. The aim of the paper is to examine whether there is a relationship between the number of disruptions and interruptions in the supply chain and reshoring activities. The results of the research can be used to identify the interruption factors that most often lead to reshoring, but also as a basis for defining recommendations for minimizing the effects of risk events.

Keywords*: supply chain, risks, reshoring, suppliers.*

1 INTRODUCTION

The past few years we have been witnesses of numerous geopolitical and crisis events that have increased the vulnerability of global supply chains and the interdependence of international value chains. Events such as the COVID-19 pandemic, the war in Ukraine, technological innovation, over-specialization, uncontrolled climate change and geopolitical tensions show how fragile the global economy and global supply chains are. The total damage to global supply caused by these events is difficult to determine because they differ in intensity and degree of interdependence. However, the World Bank estimated that the global economy could lose up to 1.2 billion dollars in 2023 due to the disruptions caused by the COVID-19 pandemic, labor shortages and the war in Ukraine. Developing countries could, due to these disruptions and high dependence on the import of goods and services, suffer damages in the amount of 426 billion dollars in 2023 [11].

The disruptions and uncertainties generated by the mentioned events continue to hover over supply chains. In order to protect against the numerous risks arising from these events, supply chains are increasingly considering the issue of reconstruction. In this sense, more and more companies are implementing a nearshoring strategy, which aims to bring production closer to the company's home country. Such a reaction by the company marks a change in the decades-long trend of relocating production or production operations to another country, known as offshoring manufacturing. The current disruptions and uncertainties contribute that some companies implement a reshoring strategy, which aims to return outsourced production, labor and technology to the company's home country. It is considered that nearshoring and reshoring are primarily location decisions [19, 5], as well as factor of supply chain sustainability factors [10, 13].
Reshoring leads to structural changes in the supplier network, carrying a significant potential to influence the resilience and sustainability of the company, and even the whole supply chain. A supply chain consists of relationships that connect a defined set of participants [9], and each participant has a unique combination of resources. First tier suppliers are in direct contact with the producer so it is easy to manage the relationship between them. However, problems usually arise with higher tier suppliers becouse the supervision and control over these suppliers is limited. By making a decision about reshoring, supply chains become shorter, and supply sources are closer to the production company, which is why a higher degree of resistance and sustainability of the supply chain is expected [8, 3].

2 RESHORING DECISIONS OF GLOBAL SUPPLY CHAINS

Reshoring is a consequence of trade wars, rising labor costs in offshore countries, sustainability concerns [7], as well as recent disruptions caused by geopolitical wars and the COVID-19 pandemic [2]. Regardless of the fact that these are globally present factors, the level of reshoring activity varies significantly between countries, as evidenced by Table 1.

Table 1 Number of reshoring cases by country from 2010 to 2020 [18]

Rank	Country	Jobs	Companies	% of jobs
1	China	58,817	896	46%
2	Mexico	27,481	111	21%
3	Canada	12,744	78	10%
4	India	7,376	27	6%
5	Japan	6,750	43	5%
6	Singapore	4,320	5	3%
7	Germany	1,971	24	2%
8	Russia	1,755	5	1%
9	Switzerland	1,539	8	1%
10	Spain	1,215	5	1%
11	Taiwan	1,121	22	1%
12	United Kingdom	1,002	14	1%
13	Luxembourg	621	5	0%
14	Italy	470	22	0%

China, Mexico and Canada are the countries with the highest number of reshoring cases. Despite its strong manufacturing tradition, Germany is ranked only seventh. Also, looking at different industries, impression is that reshoring activities are specialy present in the electrical and electronic equipment industry, considering the number of companies from these industries that have made a decision to return their production to their home country or to nearby countries.

Supply chains from this industry are most often characterized as complex due to the large number of partners involved in the production of the final product. Since each of those numerous partners can lead to the interruption of the supply chain process, it is expected that reshoring is the most present here, for the purpose eliminating those partners that threaten the functioning of the whole chain.

Table 2 Reshoring and FDI by industry from 2010 to 2020 year [18]

Rank	Industry	Jobs	Companies	% of jobs
1	Transportation Equipment	319,262	1,085	32%
2	Computer & Electronic Products	121,027	657	12%
3	Electrical Equipment, Appliances & Components	98,218	558	10%
4	Chemicals	88,661	800	9%
5	Plastic & Rubber Products	50,438	508	5%
6	Medical Equipment & Supplies	48,150	417	5%
7	Apparel & Textiles	46,060	746	5%
8	Machinery	45,857	393	5%
9	Wood & Paper Products	44,414	150	4%
10	Fabricated Metal Products	30,937	207	3%

Since the previous tables testify that reshoring is not equally represented in all countries and industries, there is a need to determine all potential motives that lead to such a decision.

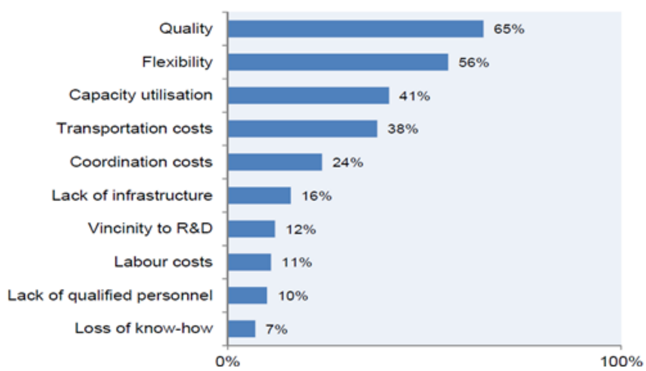

Fig. 1 Reasons for reshoring in the EU [4]

Disadvantages of outsourcing are today most often highlighted as the key motives for starting reshoring activities. Lack of quality due to outsourcing production is one of the most frequently cited reasons. Flexibility and capacity utilization are often included in the list of motives. Also, the previously mentioned costs, i.e. especially the growth of transport and labor costs. Due to the necessary sharing of information with partners about the production process and the technology used, many point to the loss of know-how as a reason of reshoring. In addition, some see the reason for reshoring in the Made in effect. Products made directly from domestic components and raw materials have an impact on consumers [6].
The list of established motives does not include exposure to disruptions and interruptions, but the fact is that all motives can lead to disruptions and interruptions. In addition, as reshoring activities always intensify with the emergence of factors that lead to disruptions or interuptions in the supply chain, there is a need to analyze the impact of disruptions and interuption in the supply chain on the reshoring decision.

3 DISRUPTIONS IN UPSTREAM SUPPLY CHAIN AS A RESHORING FACTOR

Disruptions and interruptions in the upstream supply chain are the result of choosing an inadequate supply strategy and/or suppliers who, with their available capacities, cannot meet the demands and ensure continuity in the supply chain. The occurrence of material flow disruptions or supply risks intensifies with increasing a number of outsourced parts or components and with reducing supplier base.
The stockwhip effect can be defined as a domino action of unavailability of parts or components from upstream suppliers affecting downstream customers and their sales and operational planning activities. This effect can also be defined as a supply constraint or disruption on the side of the higher tier supplier, which causes disruptions in the downstream supply chain. Supply chain partners must ensure that such obstacles are immediately eliminated or find alternative sources of supply [12], all with the aim of increasing the resilience of the whole chain.
The state of resilience is not of a static character but a process of change in uncertain and unpredictable conditions. In this sense, Hamel and Valikangas (2003) explain resilience as a dynamic process of reinventing business models and strategies according to changes in the environment [17]. An avoidance strategy can be used in this regard.
Avoidance strategy can be related to products, geographic area, market, suppliers or customers [14]. In case the company assesses that introducing a new product, entering a new market, choosing a specific supplier or customer is a risky venture, it can apply the avoidance technique, i.e. not undertaking ventures or activities that have proven to be risky [15].
In addition, if the decision was made earlier, can be change in the form of relocation of production capacities. Moving production capacities to safe locations (for example, places with a low probability of earthquakes) or cooperating with suppliers located in safe areas, focusing on markets with

constant demand, eliminating problematic suppliers from the supply base are some of the frequent actions taken, for purpose to avoid risks. Moving to another environment is the most extreme option, which acknowledges that some events are so risky that the supply chain cannot handle with them. In this situation, there is a reorganization and relocation to another market that is not exposed to the factors of disruption and interruption of the supply chain.

4 IMPACT OF DISRUPTIONS IN THE SUPPLY CHAIN ON RESHORING DECISIONS

The authors analyze the period between 2017 and 2019, in order to avoid years when global supply chains were affected by the pandemic caused by the SARS-CoV-2 virus. During the pandemic, global supply chains were faced with frequent interruptions in raw materials delivery, delays, and production stoppages due to the closure of border crossings. As a consequence of the pandemic, there is a growing understanding among managers, about the importance of shortening the supply chain and production in domestic frameworks.

Reshoring accelerated as a respond to the SARS-CoV-2 pandemic, which disrupted and interupted supply chains worldwide [16]. This strategy had the effect of increasing the number of jobs by 109,000 in the US in 2020 alone, as evidenced by Figure 2.

Therefore, in order to be more objective, the authors do not take into consideration the years when supply chains were influenced by factors whose consequences are global and extreme.

Fig. 2 The ratio of the contribution to the number of jobs of FDI and reshoring in the USA from 2010 to 2020 [18]

Are reshoring decisions really related to the number of disruptions in global supply chains in the observed period? By analyzing the number of interruptions in the supply chain and the level of reshoring (measured by the number of newly created jobs) in the observed years, the degree of correlation and the level of significance were determined.
In the case of supply chains without interruptions during the analyzed years, as well as in the case where supply chains were faced with a number of 21 to 50 interruptions, there is a negative correlation. However, statistical significance between the analyzed variables was not confirmed, as shown in Table 4.

Table 3 Number of supply chain disruptions from 2017 to 2019 [1]

Number of disruptions	2019	2018	2017
0	25.6	28	25
1-5	41.9	41	51
6-10	5.2	9	8
11-20	1.5	3	3
21-50	2.6	2	2
51+	0.7	1	1

Table 4 Paired Samples Correlations

No. of disruptions/Reshoring		N	Correlation	Sig.
Pair 1	0 – Reshoring	3	-.120	.924
Pair 2	From 1 to 5 – Reshoring	3	.781	.430
Pair 3	From 6 to 10 – Reshoring	3	.758	.452
Pair 4	From 11 to 20 – Reshoring	3	.899	.289
Pair 5	From 21 to 50 – Reshoring	3	-.899	.289
Pair 6	More than 51 – Reshoring	3	.899	.289

Source: Authors

These results are not a big surprise since all interruptions in global supply chains are included in the analysis, regardless of the causes that led to them. Since the authors especially emphasize the sources of supply, i.e. suppliers as interruption factors and the reason for reshoring decisions, there is a need to analyze the relationship between interruptions caused by different tiers of suppliers and reshoring decisions. In order to analyse the resilience of supply chains, the Business Continuity Institute assesses the extent to which tier of suppliers are responsible for disruptions and interuptions in supply chain processes (Table 5).

Table 5 Suppliers as a disruption factor in the supply chain from 2017 to 2019 [1]

Supplier	2019	2018	2017
First tier supplier	48.9	52	44
Second tier supplier	24.9	23	24
Higher tier (3th, 4th, ...)	12.2	11	10

First tier suppliers are in direct contact with the manufacturer, while second, third, or higher tier suppliers represent the supplier's suppliers. Since reshoring implies a change in the source of supply in the context of reducing geographical distance, the author's assumption is that reshoring can ensure a reduction in the number of interruptions caused by suppliers, for the reason that the newly chosen sources of supply will be closer to the manufacturer and the production process, i.e. in the home country.
The correlation between different suppliers' tier, as a cause of interruptions in the supply chain and reshoring activities,

is negative, what can be concluded according Table 6. The highest correlation is in the case of highest tier suppliers. Statistical significance was confirmed only at this tier supplier. In the case of first and second tier suppliers, the increase of reshoring activities is expected to lead to a reduction in disruptions caused by first and second tier suppliers. However, statistical significance does not exist between the analyzed variables.

Table 6 Paired Samples Correlations

Tier/Reshoring		N	Correlation	Sig.
Pair 1	First tier supplier – Reshoring	3	-.550	.629
Pair 2	Second tier supplier – Reshoring	3	-.534	.641
Pair 3	Higher tier – Reshoring	3	-1.000	.011

Source: Authors

Table 7 presents a t-test of pairs of interruptions caused by suppliers of different tiers and reshoring activities. Two-way statistical significance for all analyzed variables is less than 0.05, which indicates that there is a significant statistical difference between reshoring activity and the number of interruptions caused by different tiers supplier. Therefore, the increase in reshoring activity leads to a decrease in the number of interruptions caused by the actions of different tiers supplier.

Table 7 T-test pairs

	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Pair 1	61285.03333	20552.96936	11866.26239	10228.62705	112341.43961	5.165	2	.036
Pair 2	61309.36667	20551.25789	11865.27428	10257.21192	112361.52142	5.167	2	.035
Pair 3	61322.26667	20551.85153	11865.61701	10268.63724	112375.89609	5.168	2	.035

Source: Authors

4 CONCLUSION

Companies' need for nearshoring and reshoring is likely to increase. The orientation towards just-in-time supply chains and cost minimization is changing in favor of a holistic approach focused on resilience. In the coming months and years, companies are likely to increasingly implement nearshoring and reshoring strategies to increase the resilience of supply chains around the world. However, despite the fact that these strategies are gaining more and more importance, this does not mean the beginning of the end for offshoring [16].

The results presented in the paper prove that not all causes of disruptions and interruptions in the supply chain are equally important for reshoring activities. The second part of the analysis highlights higher tier suppliers, in the sense that they are most responsible for reshoring decisions, can be explained by the level of established relationships between suppliers. Since, as already pointed out, the relations between the manufacturer and the first tier suppliers are direct, usually based on trust, the manufacturer will not so easily give up these suppliers; even when they are the source of disruptions and interuptions of the chain. This only indicates that the manufacturer, having invested a lot in building partner relations, expects to lose more by making a reshoring decision in relation to the first tier supplier, than he would gain by changing the source of supply.

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ADVANTAGES OF USAGE OF POWER - OPERATED STORAGE EQUIPMENT

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Abstract

Storage systems are commonly static load bearing steel racking structures for the storage and retrieval of the goods in warehouses that use order pickers, industrial trucks or stacker cranes as handling equipment. Although today the static racking components and material handling equipment are well - known and applicable by the most of the end – users and at the same time standardised by the manufacturers, there are many cases when their simultaneous application is not adequate with need for the application of power - operated storage equipment. Within this paper, classification, definition of the main parts and description of the principles of functioning are preceding the discussion on advantages of usage of power - operated storage equipment like carousels, lifts and mobile racking and shelving.

Keywords: *storage, equipment, power – operated, automatization.*

1 INTRODUCTION

In the last decades of the XX century, there was an intensive development of storage technology. The daily increase in production creates a surplus of products that must be stored. Modern production and distribution needs imposed by the competitive market, as well as the need for the best possible use of expensive storage space, which today is to a considerable extent potentiated by the lack and permanent increase in the price of construction land and especially by the tightening of environmental requirements, affect the development and construction of warehouses. Many already existing storage systems very well accomplish the basic task of the warehouse: to receive, store and deliver safely and with efficient monitoring, the largest amount of goods in the shortest possible time on the smallest possible space, with fewer people as much as possible. However, each of the systems contains their advantages and disadvantages, so a very good knowledge of each of them is needed, so that in a specific case the most favorable solution can be chosen, i.e the one in which the basic characteristics come to full expression. In modern warehouses, in order to make better use of the available volume, palletized goods are most often placed in appropriate racking structures. In order to meet the requirements of modern storage, most of the world's well - known manufacturers have developed a program of almost all types of storage racks. For the purpose of storing and picking up the goods in warehouses, static load bearing steel racking structures that are serveced by order pickers, industrial trucks or stacker cranes as handling equipment are most often used. Table 1 shows the types of storage systems accoding to the type of unit load and its moving through the racking structure [1]. Racking components are produced today in most cases, on modern production lines and in large series, which guarantees the constant quality of the offered products. Simultaneously, accompanying material handling equipment are well – known, developed and applicable by the most of the end - users too. But, restrictions of modern production such as available and expensive space, lack of the manpower and increasingly strict safety and environmental requirements or specific working conditions dictate more and more the need for the application of power - operated storage equipment. The result is that items are stored compactly in a confined space and delivered to the operator as requested.

This increases productivity and eliminates unproductive operator travel within the warehouse, errors, injuries, etc.

Table 1 Types of storage systems [2]

No.	Type of Unit Load	No.	Storage system
1	Palletized Goods	1.1	Adjustable pallet racking
		1.2	Drive-in and drive-through pallet racking
		1.3	S/R machine pallet racking
		1.4	Open face pallet racking
2	Small Parts Mechanically Handled	2.1	Open face miniload racking
		2.2	Multi-location miniload racking
3	Small Parts Hand Loaded	3.1	Shelving
		3.2	Multi-tier shelving
		3.3	Cantilever shelving - Gondola
4	Long Unit Loads	4.1	Cantilever racking
		4.1	Cassette racking
5	Dynamic Storage Palletized Goods	5.1	Mobile racking
		5.2	Pallet live storage
		5.3	Shuttle racking
6	Dynamic Storage Small Parts	6.1	Mobile shelving
		6.2	Carton live storage
		6.3	Carousels
		6.4	Storage lifts
7	Various	7.1	Mezzanine floor
		7.2	Raised floor
		7.3	Rack-clad

2 TYPES OF POWER – OPERATED STORAGE EQUIPMENT

According to the references [1, 2] there are following types of power – operated storage equipment:

- carousels,
- storage lifts,
- mobile racking and
- mobile shelving.

Carousels are horizontal (shown in figure 1 a)) or vertical (shown in figure 1 b)) circulating storage equipment with load carriers (freely suspended carriers, suspended rods or others) [2].

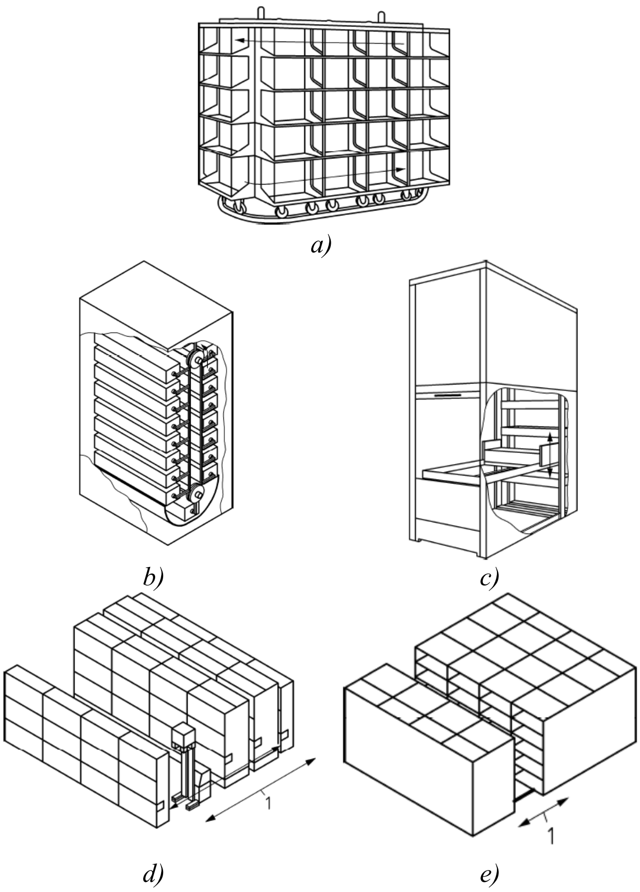

Fig. 1 *Power – operated storage equipment: a) horizontal carousel, b) vertical carousel, c) storage lift, d) mobile racking, e) mobile shelving* [3]

Storage lifts shown in figure 1 c) are designed to take goods placed on load carriers (e. g. storage containers). The in-built lift unit carries the load carriers (e. g. storage containers) from an access opening to storage locations in a racking tower, or from a storage location to an access opening [2]. Storage lifts can have one or more access openings on one or more levels.

Mobile racking comprises a skeleton framework of fixed or adjustable design supporting unit loads generally without the use of shelves [2]. This skeleton framework is in turn fixed to movable base units supported on wheels mounted in the base unit, which run on rails mounted in the floor. The system is designed for the storage of unit loads where loading or unloading is generally by mechanical means (see figure 1 d)).

Mobile shelving comprises a series of hand loaded adjustable load carrying surfaces (shelves) supported by upright frames all of which is in turn fixed to a movable base unit. This base unit is supported on wheels mounted in the base unit which run on rails mounted in or on the floor [2]. The system is designed to be loaded by hand with multiple loads all of which are substantially less than the total carrying capacity of the shelf. The system is not designed to be loaded or unloaded by mechanical equipment (see figure 1 e)).

3 MAIN FEATURES AND PARTS OF POWER – OPERATED STORAGE EQUIPMENT

Comparing to stand - alone workstations horizontal carousel storage system is the ideal designed solution to store and retrieve small and medium - sized items quickly, reliably and cost - effectively whether in production or distribution in a low - ceiling and large warehouse footprints. As shown on figure 2, the carousel consists of carriers (bins) mounted on an oval track that rotate horizontally and deliver stored goods to the worker. As the drive machinery is located inside the shelving, and adjustable shelf heights maximize the use of space, the footprint reduction can be significant. Racks are often left open but can be fenced off for security. The requested items are delivered to the operator located in the picking zone quickly, directly, and reliably – eliminating travel and search times commonly associated with traditional manual inventory systems. Every carousel uses one of the many integrated pick - to - light technologies to indicate the active carousel, shelf level and quantity of items to pick, making batch picking simple, fast and easy. In addition to achieving most of the advantages provided by power – operated equipment, these carusels have two main disadvantages in term of fixed pick heights which cause less ergonomic and don't leverage vertical space, if available. However, in some cases horizontal carousels can be stacked on top of each other to make use of vertical space. But that solution can be economically unjustified. So, they are best for large areas with low ceilings, for small to medium heavy items, high depth of inventory and large batch sizes and order numbers [4].

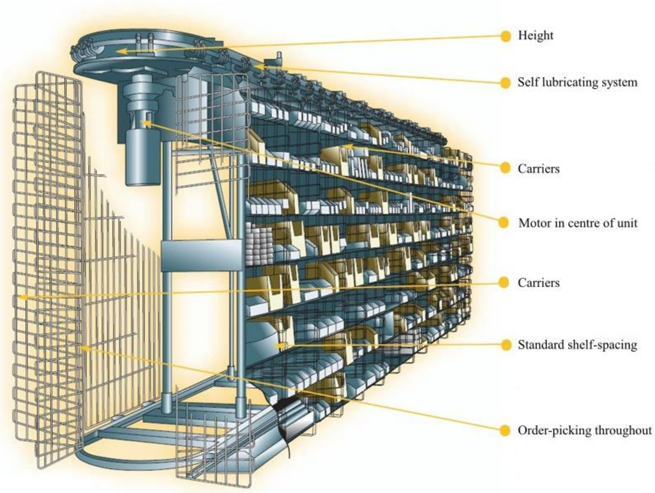

Fig. 2 *Horizontal carousel*

In connection with previous one, although with similar name, with the main difference in the way of rotation which is now vertical, operate vertical carousels available in a wide range of sizes and capacities. They are fully automated vertical storage and retrieval systems that take up a minimum footprint by utilizing the ceiling height available. They also operate according to the logic of “materials towards the operator”. It is composed of a series of carriers mounted in a fixed locations to a chain drive thus forming a vertical closed - loop track, inside a metal enclosure. Powered by a motor it transports inventory in a vertical loop, resembling the movement of a ferris wheel as shown on figure 3. Vertical carousels have lower storage density than equivalent sized horizontal carousels, but smaller footprints. Main disadvantages of these machines are their speed, since they are slower than horizontal carusels and items must be uniformly distributed to avoid unbalanced loads. They are best for heights up to 10 m, secure/controlled items, items requiring climate control, uniform bin sizes and shelf weights [4].

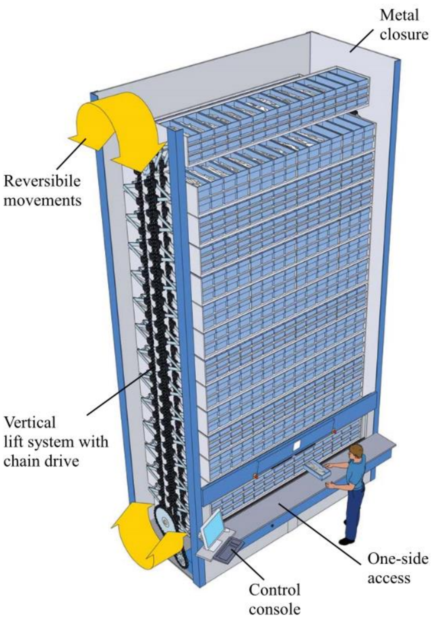

Fig. 3 *Vertical carousel*

Based on the same principle of the functioning “goods-to-person”, within storage lift an extractor collects individual trays from where they sit in the machine and then delivers the item to a picking bay, i.e. items can be retrieved without rotating everything stored inside the system. While a vertical carousel rotates every time the user needs to pick or replenish an item, vertical lift modules only present the tray with the required item. The linear rather than rotating movement means no unbalanced loading problems and that even heavy items can be stored and retreived safely. Due to the movement of every bin during warehouse operations, the vertical carousel is not the ideal choice when storing fragile products or items that are sensitive to continuous movement, such as glass. Another important difference to take into account is the height of the products you need to store. While vertical carousels have height restrictions in regard to their trays, vertical lift module trays can be modified to fit your inventory. Units can have flexible tray heights, meaning many different sizes of items can be stored without compromising on overall storage density. Vertical lift modules are composed of two tray towers - one in the front and one in the back - along with a central elevator. While a vertical carousel cannot work from both accesses opening simultaneously, a vertical lift module can [5].

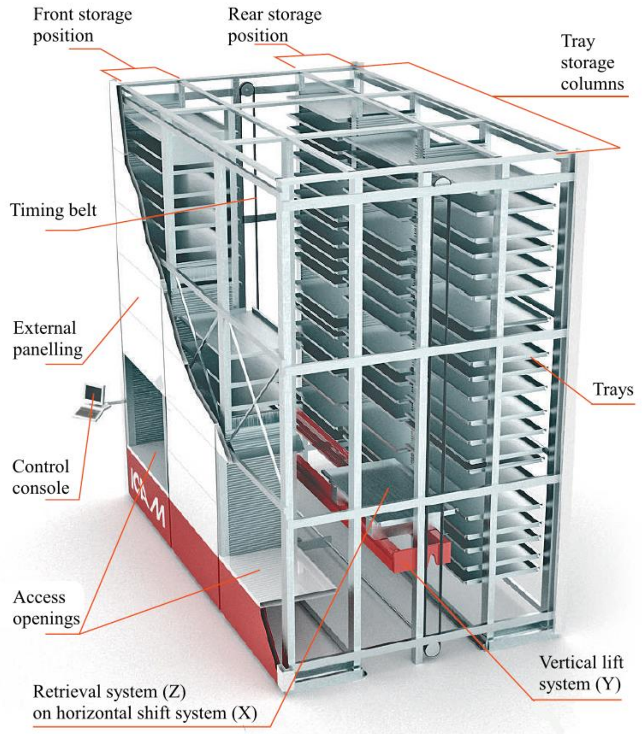

Fig. 4 *Vertical lift module* [6]

Mobile racking is a high-density storage system with racking mounted on mobile bases that run on rails and allow stock to be accessed by opening just the relevant isle as shown on figure 5. They provide over 80% extra storage compared to a traditional, static racking system in the same floor space. Mobile base units allow movement of the racking and are chosen according to the size and weight of the stored material. Each wheel of the unit can carry adequate weight. Each storage system is guided by at least two guide rails and one or more runners which vary in size according to the load the base units must carry.

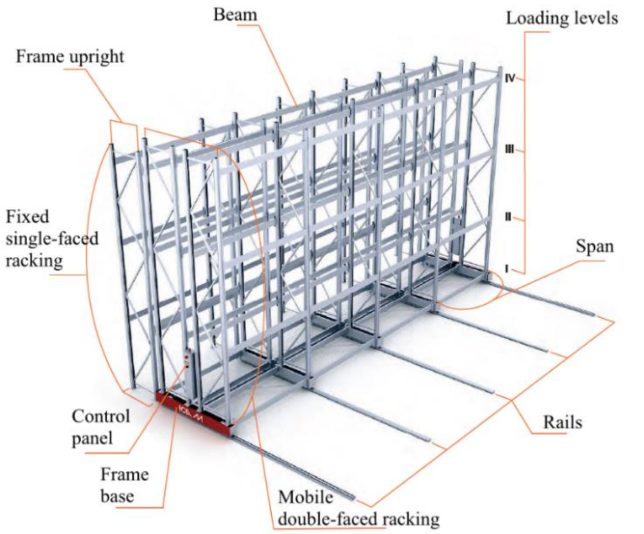

Fig. 5 *Mobile racking* [6]

Beside conventional pallet racking that can be mounted on mobile base units making them ideal for the storage of any type of material from pallets, containers and coils, the mobile bases are sutiable for carrying of cantilever racks too for long lengths items or sheet steel or even multiple shelves for odds and ends or loose material [6].

By eliminating almost all the aisle space, mobile shelving similar to previous mentioned mobile racking increase capacity comparing traditional shelving [6]. Various type of shelving and accessories mean that mobile shelving can easily be adoped to different types of material and methods of filing. Serving of this type of racks is only possible by manpower which is their main disadvantages.

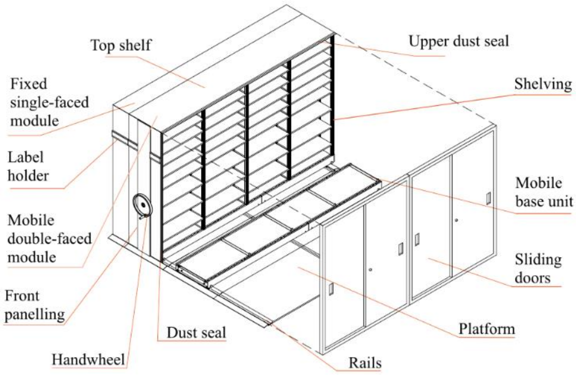

Fig. 6 *Mobile shelving* [6]

Analyzing the above-mentioned characteristics of power – operaded storage equipment, their advantages and disadvantages in term of space usage, labor cost, picking accuracy and throughput, inventory control and ergonomics can be summarized as shown in table 2.

Table 2 Pros and cons of all types of powered – operated storage equipment

No.	**Description**	**Horizontal Carusel**		**Vertical Carusel**		**Vertical lift module**		**Mobile racking**		**Mobile shelving**	
		+	-	+	-	+	-	+	-	+	-
1	Floor Space	√		√		√		√		√	
2	Space height		√	√		√		√			√
3	Labor cost	√		√		√			√		√
4	Picking Throughput	√		√		√			√		√
5	Picking Accuracy	√		√		√			√		√
6	Inventory control	√		√		√			√		√
7	Ergonomics		√	√		√			√		√

4 CONCLUSIONS

This paper discussed benefits of power – operated storage equipment, which are mainly automated machines, over conventional rack and shelving equipment used in modern warehouses in either a production or distribution setting. All mentioned power – operated storage equipments meet warehouse requirements especially in terms of saving space, reducing labor costs, increasing throughput and improving accuracy, inventory control and ergonomics. Primarly removing the wasted aisle space which traditional static warehouse system requires and utilizing the building heigh as much as possible, this type of machines provide high density storage with better floor space utilization. Delivering the required item directly to the operator via the "goods to person" concept, powered – operated storage equipment significantly reduce operator walk and search time which is usually dominantly wasted time. Starting from the previously mentioned "goods to person" delivery concept, compared to manual work these systems multiply the throughput, minimum double. The traditional manual picking process provides more opportunity for human error. These equipmet integrate with a variety of picking technologies and integrated message centers that communicate pick information to the operator for high pick accuracy. Machines provide controlled inventory management and usually interfaced with a facility's warehouse management system and enterprise resource planning systems. Additional improvement of inventory turn can be achieved by implementation of FIFO (first in, first out) or LIFO (last in, first out) picking processes. At the end, each system depending on its features significantly improve ergonomics through reducing operators walking, bending or stretching or generally reduce occurrence of injuries and therefore additional costs for the company.

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til 2023

WESTERN BALKAN COUNTRIES MULTI-CRITERIA EVALUATION: LOGISTICS PERFORMANCE INDEX

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Abstract

Logistics is now one of the essential components of economic activity as a result of globalization and rising competition. Product mobility is made more straightforward by effective logistics services, which also guarantee their safety, promptness, and cost-effectiveness while trading them between different countries. The LPI was developed as an interactive examination tool to assist economies in identifying the possibilities and difficulties they have in their performance on trade logistics and what they can do to enhance their performance. The World Bank designed the LPI. The Logistic Performance Index (LPI) examines regional variations and offers a broad overview of customs practices, logistics expenses, and the standard of the infrastructure required for overland and marine transit. The ranking of countries based on LPI scores for 2023 is the primary objective of the current research. The performance of the Western Balkan countries will be assessed in terms of the logistical characteristics from which the LPI was derived, using the CoCoSo (Combined Compromised Solution) approach for multi-criteria decision-making. The anticipated outcomes based on the aforementioned approach should identify the Western Balkans' top logistics provider and offer recommendations for expanding the logistics industry to other economies.

Keywords*: logistics performance index, CoCoSo, decision making process, logistics management, performance management.*

1 INTRODUCTION

In the challenging and dynamic times of global commerce, logistics emerges as a critical pillar, shaping the efficiency and competitiveness of economic activities across nations. The ability to move products efficiently not only forms the backbone of trade but also acts as an important factor in maintaining the competitiveness of nations. Effective logistics not only facilitate this mobility but also ensure the safety, timeliness, and cost-efficiency of traded goods, contributing to robust economic interactions among countries [1]. Data from the World Bank indicate that a 10% improvement in logistics performance can lead to a growth of up to 2% in GDP for low-income countries, underscoring the substantial impact of logistics on economic activities [2]. Consequently, the seamless transport of goods across national frontiers has become a critical factor for economic advancement in an increasingly interconnected global marketplace. The Logistics Performance Index (LPI), introduced by the World Bank, stands as a testament to the growing recognition of logistical prowess as a determinant of trade performance [2]. The LPI functions as a diagnostic tool, dissecting the complex ecosystem of trade logistics to illustrate how economies can improve their logistic capabilities. It encompasses a comprehensive evaluation of factors including customs procedures, logistics costs, and the quality of relevant infrastructure for both overland and maritime transport [3].

2 LITERATURE BACKGROUND

Global logistics has increasingly been recognized as a fundamental component of international trade and economic efficiency. The concept involves not just the transportation of goods but also the management of information, inventory, warehousing, material handling, and packaging [4].
The measurement of logistics performance has evolved significantly over time, influenced by technological advancements, globalization, and the increasing complexity of supply chains. In the initial stages of formalizing logistics performance, metrics were heavily focused on internal operational efficiency—mainly cost and time. The 1960s and 1970s saw logistics primarily concerned with transportation and warehousing, where metrics such as turnaround times, vehicle utilization, and cost per shipment were [5]. The 1980s marked a shift towards integrated logistics systems. Researchers like Bowersox and Closs began advocating for a holistic approach, combining transportation, warehousing, inventory management, and material handling into a single, optimized process [6]. The impact of logistics on international trade began to garner attention, with studies examining how logistical efficiency could reduce trade barriers and improve competitiveness [7].

Recognizing the need for a comprehensive measure that captured the complexities of global logistics, the World Bank introduced the Logistics Performance Index (LPI) in 2007. The LPI was revolutionary because it provided a multidimensional assessment of logistics performance, capturing elements such as the efficiency of customs clearance, quality of trade and transport infrastructure, ease of arranging shipments, competence, and quality of logistics services, tracking and tracing, and timeliness [8].

Since its inception, the LPI has been updated and refined to better reflect the changing dynamics of global logistics. It has included perspectives from various stakeholders, such as international freight forwarders and express carriers, to provide a more detailed and accurate picture.

With the increasing prominence of e-commerce and digital technologies, the metrics of logistics performance continue to evolve. Today's performance measurement not only includes traditional metrics but also factors such as sustainability, resilience, and agility [9-11].

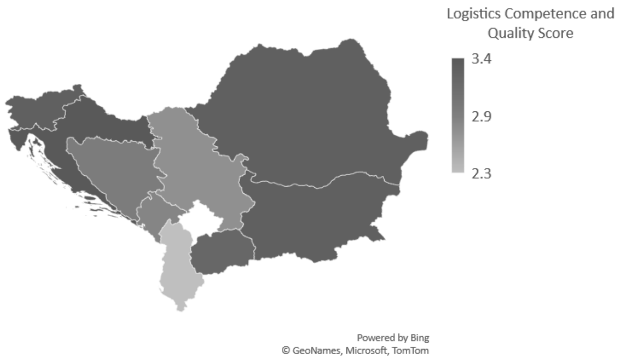
Several studies have established a direct correlation between logistics performance and economic outcomes. Researchers [12] quantified the impact of logistics on trade volume, finding that a 10% improvement in LPI scores correlates with a significant increase in trade. Regional disparities in logistics efficiency are often highlighted in the literature, showing a divide between developed and developing nations [13]. Rodrigue [1] emphasizes the challenges faced by emerging economies due to inadequate logistics infrastructure as important.

Quality of service, infrastructure, and ease of arranging competitively priced shipments are identified as the main determinants of logistics performance [14,15]. The role of technology and digitalization in facilitating these determinants is also a growing focus. New methodologies, such as data envelopment analysis (DEA) and stochastic frontier analysis (SFA), have been used to measure logistics efficiency more accurately [16]. Moreover, policy reforms can significantly improve logistics performance. Researchers [17] provide evidence that improvements in trade facilitation measures are closely linked to better logistics performance.

3 METHODOLOGY

This research is based on the latest iteration of the LPI, focusing on the 2023 rankings, with a particular focus on the Western Balkan countries. Given the strategic significance of the region, a detailed examination of its logistical framework is vital. This study adopts the CoCoSo (Combined Compromised Solution) methodology for multi-criteria decision-making, a robust approach for evaluating multifaceted systems like logistics [18-20]. By applying CoCoSo, authors aim to analyze the logistics performance of the Western Balkans and, consequently, identify the leading logistics provider within this cluster of economies using the following and selected LPI component indicators (subindicators) (Figure 1):

- Infrastructure score
- Logistics Competence and Quality Score
- Tracking and Tracing Score
- International Shipments Score.



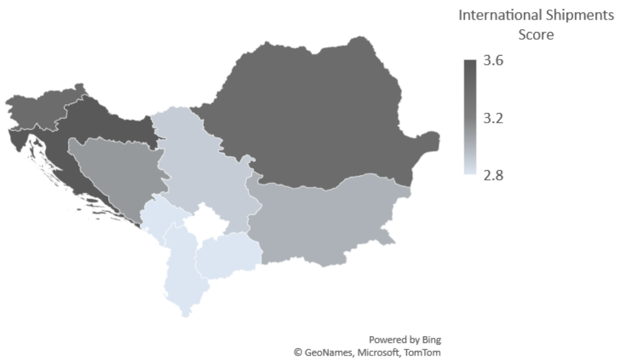


Fig. 1 Descriptive statistics for analyzed LPI subindicators in Western Balkans economies map chart
Source: Authors elaboration

4 RESULTS AND DISCUSSION

The power of weighted comparability (Pi) and sum of weighted comparability sequence scores (Si) are computed for each of the alternatives after conducting the initial matrix with equal criteria weights of LPI components' indicators (Table 1).

Table 1 Exponentially weighted comparability and sequences Si and Pi

Weights of criteria	0.25	0.25	0.25	0.25
Alternatives	**C1**	**C2**	**C3**	**C4**
Albania	2.838	3.112	2.884	2.800
Bosnia and Herzegovina	2.885	3.221	3.226	3.100
Bulgaria	2.642	2.927	2.903	3.000

Croatia	2.914	2.674	2.492	3.600
Montenegro	3.384	3.213	3.085	2.800
North Macedonia	3.325	3.053	3.135	2.800
Romania	3.264	3.279	3.187	3.400
Serbia	3.124	3.412	2.994	2.900
Slovenia	3.169	3.402	3.382	3.400
Exponentially weighted comparability and sequences Si and Pi	**Si**			**Pi**
Albania	0.3245			2.4094
Bosnia and Herzegovina	0.5670			3.4197
Bulgaria	0.2637			2.2966
Croatia	0.3416			1.7781
Montenegro	0.5992			2.8280
North Macedonia	0.5392			2.7481
Romania	0.7973			3.7791
Serbia	0.5847			3.3591
Slovenia	0.8617			3.8453

Source: Author's calculation

The Western Balkans' top logistics provider is Slovenia. The second and third place after conducting CoCoSo is reserved for Romania and Serbia respectively (Table 2).

Table 2 Final alternatives ranking according to LPI components

Alternatives	K	Final Ranking
Albania	1.5925	**7**
Bosnia and Herzegovina	2.4426	**4**
Bulgaria	1.4394	**8**
Croatia	1.3499	**9**
Montenegro	2.2419	**5**
North Macedonia	2.1052	**6**
Romania	2.9900	**2**
Serbia	2.4467	**3**
Slovenia	**3.1280**	**1**

Source: Author's calculation

5 CONCLUSION

The projected findings from this approach are poised to offer a dual benefit: pinpointing the frontrunners in logistics within the Western Balkans and generating actionable insights that could propel the expansion of the logistics sector in comparable economies. Ultimately, this study seeks to contribute to the ongoing discourse on logistics optimization and its effect on regional and global economic landscapes. Slovenia has earmarked EUR 17 billion to improve logistics and transportation facilities through 2030 and has also adopted a transport development strategy, a national traffic development plan, and an alternative fuels strategy. The government is also encouraging further digitalization in transport and logistics to eliminate red tape and reduce costs. In addition, nine business facilitation zones located throughout the country offer foreign business partners a chance for public-private partnership projects.

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THE USAGE OF ENERGY-EFFICIENT DRONES IN INTELLIGENT, ECO-FRIENDLY TRAFFIC MANAGEMENT

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Abstract

In the field of traffic management, the integration of drones and artificial intelligence (AI) is revolutionizing how we supervise, optimize, and enforce traffic regulations. Drones, equipped with sensors and AI algorithms, enhance traffic management by enabling real-time identification of issues through computer vision and anomaly detection, providing live video feeds for rapid incident assessment, predicting traffic patterns, optimizing signal lights using machine learning (ML) models, and improving road safety through license plate recognition and speed detection algorithms. This study introduces an innovative approach involving tethered drones for algorithm development, transfering them to untethered drones for sustainable and efficient traffic management. This strategy ensures a resourceful and environmentally responsible approach to traffic management.

Keywords*: Unmanned Aerial Vehicle (UAV), Energy Efficiency, Artificial Intelligence (AI), Traffic Management, Algorithm Development.*

1 INTRODUCTION

In recent years, Unmanned Aerial Vehicles (UAVs), have emerged as versatile tools with the potential to revolutionize various fields, including traffic management. These aerial vehicles have come a long way since their early days, initially associated with military endeavors and often referred to as 'drones.' The term 'drone' gained prominence during World War II when the U.S. military employed radio-controlled aircraft for target-finding exercises. Over time, technology has transformed these aerial vehicles, expanding their roles beyond military use. Therefore, drones have become invaluable tools in surveillance, reconnaissance, and even combat. UAVs represent flying robots, typically controlled remotely through built-in sensors and GPS technology.

Their applications have diversified, encompassing search and rescue operations, traffic management and weather monitoring, firefighting, as well as recreational hobbies and entertainment. The UAV operates as a comprehensive system, comprising two primary components: the aerial craft itself and the ground-based control system. The effective functionality of this system relies heavily on the third crucial element, the communication and data exchange system. UAVs operate in two fundamental modes: flight and navigation. To enable flight, UAVs require a power source, typically batteries or fuel, and essential components like rotors, propellers, and the frame to maintain their airborne status. The design of the UAV frame often employs lightweight composite materials to enhance maneuverability while reducing overall weight. Communication is facilitated through radio waves, such as Wi-Fi. Furthermore, they may feature GPS, obstacle detection, collision avoidance, cameras, and specialized software. These elements, controlled via a dedicated remote unit and intelligent software, enhance the drone's performance and versatility.

In order to perform its functions properly, a drone needs a sufficient amount of energy. In that sense, this paper explores the possibilities of artificial intelligence (AI) and its algorithms, investigating their potential in optimizing energy efficiency for drones while executing tasks related to traffic monitoring and traffic flow optimization.

2 REVIEW ON RECENT RELATED RESEARCH TRENDS

A significant rise in UAV research across a wide spectrum of areas has encompassed notable domains including antennas, aircraft recognition, remote data collection, deep learning, reinforcement learning, machine learning (ML), flight control, IoT applications, power management, and energy conservation. The integration of AI tools has significantly elevated UAV capabilities, particularly in tasks related to object recognition, route optimization, and operational planning [1]-[8]. Additionally, areas such as human-drone interactions, group dynamics of drones, environmental monitoring, safety protocols, multi-platform integration, and legal and ethical considerations have gained prominence [1]-[2].

The utilization of UAV systems across diverse domains underscores the importance of integrating this mechatronic device with areas such as aircraft surveillance, data collection, AI, IoT, and flight controls. The data underscores the interconnected nature of these research fields within UAV technology, hinting at collaborative and streamlined solutions in the near future [3]-[4]. Given the primary focus of this paper on enhancing drone energy efficiency, particularly through the exploration of AI algorithms, the subsequent sections will provide in-depth insights into these two critical areas of research.

2.1. Efficient Flight Dynamics in UAVs

Promoting energy-efficient flight dynamics is pivotal in UAV research, focusing on crafting drones that maintain prolonged flight durations with nominal energy expenditures [9]-[10]. Such efficiency is integral for augmenting UAV functionalities, encompassing flight duration, carriage weight limits, and operational reach [11]-[12]. Several strategies, are under scrutiny, including advancements in aerodynamic shaping, the employment of featherweight materials, and harnessing alternative energy reservoirs, such as solar energy [13]-[14].

One fundamental challenge in ushering energy efficacy is curtailing UAV mass. In response, there's a heightened interest in utilizing light materials like composite blends and innovating manufacturing methodologies that trim down UAV weight. Moreover, refining propulsion mechanisms is vital for securing energy frugality, encompassing the adoption of high-yield engines and pioneering propulsive technologies. Research is also veering towards the assimilation of electric and hybrid power systems, which promise superior energy thriftiness over conventional combustion engines [15].

Another intriguing research avenue is channeling alternative power sources, notably solar energy. This involves the evolution of light, efficient solar units and enduring energy storage mechanisms, ensuring consistent power provision. Such efficient flight dynamics hold the promise of amplifying UAV competencies, unlocking new functionalities and operational horizons [16].

However, extensive data exchanges, particularly during surveillance and communication tasks, can lead to communication lags and spike energy consumption. In such scenarios, deep reinforcement learning (DRL) and other AI methodologies are becoming increasingly pertinent [17].

2.2. AI Integration in UAV Systems

In recent times, AI's incorporation has profoundly influenced the UAV sector. AI's ability to empower UAVs to act on their own has augmented their efficiency across various functions. Advancements due to AI integration in UAVs encompass aspects like object monitoring and pursuit, route determination, self-directed navigation, collective intelligence of swarms, visual data assessment, and cybersecurity measures [5]-[8].

Prominent AI models, including Convolutional Neural Networks (CNNs) and Recurrent Neural Networks (RNNs), have been employed to identify and monitor aerial vehicles, diverse objects, and real-time entities using UAVs. Such applications extend to realms like surveillance, urgent search missions, and farming. AI also equips UAVs with the capability to traverse autonomously in intricate settings, avert obstacles, and arrive at real-time verdicts anchored in sensor feedback. This has a bearing on fields such as parcel delivery, structural scrutiny, and observation. Furthermore, AI techniques facilitate the synchronized operation of multiple UAVs, enabling them to collaboratively accomplish tasks. This is particularly important in emergency responses, monitoring activities, and defense initiatives [18]-[19].

AI has also been harnessed to decode visuals taken by UAVs, helping in tasks like pinpointing objects, discerning content segments, and detecting aberrations. Such proficiencies find applications in agriculture, ecological observation, and calamity management. Ensuring the digital safety of UAVs, AI aids in recognizing and averting potential cyber threats, crucial for both defense missions and civilian UAV operations [20]-[21].

A few exemplary studies showcasing AI's role in UAVs that have gained research traction include DRL for UAV steering, vision-directed UAV landings, swarm logic for unified UAV task charting, UAV self-navigation in confined spaces, and AI-driven object tracking for UAV-based observation. These instances reflect the expansive application spectrum of AI within the UAV domain, spanning navigation, strategizing missions, object monitoring, and protective surveillance [22].

The landscape of UAV operations is being transformed by AI algorithms. These algorithms enhance UAVs with superior self-guided flight and decision-making proficiencies, paving the way for safer and more efficient functions. Advanced sensor systems, encompassing computer vision and LIDAR, represent a fusion of AI and ML in UAVs. Real-time data from these sensors feed the AI systems, empowering UAVs to respond dynamically to environmental shifts. Computer vision aids UAVs in identifying entities and individuals, elevating safety by averting possible collisions. Concurrently, LIDAR offers intricate insights into the UAV's environment, detailing attributes like object distance, dimension, and velocity, facilitating better navigation in multifaceted settings [23]-[24]. AI also influences UAVs by refining their flight trajectories. Leveraging ML, UAVs can draw from historical flights to tweak their routes, ensuring energy conservation and enhanced operational efficiency by considering variables like wind patterns and ambient temperature.

3 UAV TRAFFIC APPLICATIONS

3.1. Traffic Monitoring and Surveillance

The integration of Unmanned Aerial Vehicles (UAVs) in Road Traffic Monitoring (RTM) systems has garnered significant interest due to its potential for automating various aspects of the transport sector [25]. Drones equipped with cameras and sensors offer a cost-effective solution for monitoring extensive road segments, surpassing the capabilities of conventional devices like microwave sensors and video surveillance cameras.

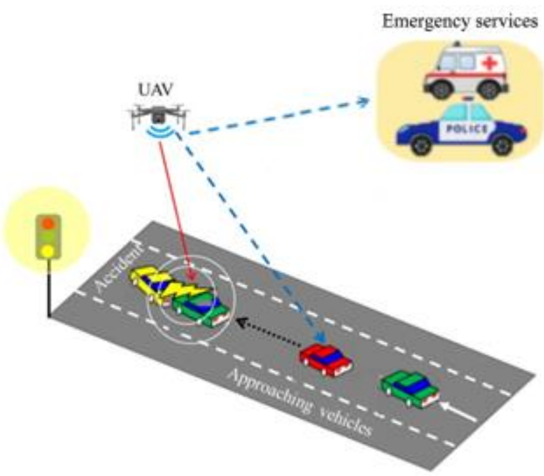

Fig 1. *UAV for road assistance*

In the realm of law enforcement and public safety, drones prove invaluable. They provide a clear aerial view for local police, aiding in tasks such as monitoring traffic accidents, conducting security raids, and addressing criminal activities like car theft and dangerous driving. An overview of the potential services provided by drones on the highway is shown in Fig. 1. The applications extend to vehicle identification, pursuing suspects, and detecting speeding vehicles to prevent traffic congestion.

A key advantage of drones lies in their ability to monitor road conditions, identifying issues such as cracks and potential hazards. The integration of AI algorithms enhances the efficiency of data analysis. Traffic-related applications, such as Traffic Monitoring and Surveillance, Incident Management, Traffic Flow Optimization, and Automated Traffic Enforcement, leverage AI-driven methodologies for optimal results.

Drones, with their capacity to cover vast areas, offer a comprehensive overhead perspective of transportation pathways. The data they collect includes insights into traffic flow, bottlenecks, and incidents like accidents or obstacles. AI algorithms, particularly those rooted in computer vision, play a crucial role in analyzing the visual data captured by drones. Convolutional Neural Networks (CNNs) can identify and monitor various elements such as vehicular movements, pedestrians, road demarcations, and signage.

Additionally, AI applications in traffic management using drones extend to anomaly detection. Techniques like Isolation Forests or One-Class Support Vector Machines (SVMs) excel in identifying deviations in traffic dynamics, potentially indicating accidents or blockages. Optical Flow algorithms contribute to tracking object trajectories in video sequences, aiding in vehicle movement tracking and congestion identification.

3.2. Incident Management

Drones fortified with AI prowess act as invaluable assets in handling roadway incidents. Upon the report of events like collisions or vehicular malfunctions, a drone can be swiftly mobilized for evaluation. These drones transmit real-time video streams to traffic control hubs, granting on-site personnel immediate insights into the unfolding situation. Such immediate visuals become indispensable for swift determinations regarding resource distribution and emergent actions. Onboard AI techniques facilitate the discernment of incident gravity, tally of affected vehicles, and potential safety risks. Such insights equip first responders with a clearer strategy for intervention. At times, drones might also play a role in managing crowds at crash sites or other occurrences, bolstering the safety of both the intervention team and bystanders.

Incident Management Techniques like Object Detection are such models that have the capability to pinpoint specific entities or events within drone-captured footage, be it impaired vehicles, roadway obstructions, or harmed persons. Image Segmentation represents a semantic segmentation technique that allows for the breakdown of images into distinct categories, facilitating easier recognition of incident magnitude or impacted zones. Through Natural Language Processing (NLP), textual or auditory content can be analyzed to glean insights from distress signals or incident descriptions, subsequently juxtaposed with drone imagery for a holistic understanding of the incident's specifics and locale.

3.3. Traffic Flow Optimization

The utilization of AI is pivotal in refining traffic movement, drawing insights from data garnered from drones and various other mediums. Drones relay up-to-the-minute traffic data. This data, when amalgamated with information from road detectors, surveillance cameras, and vehicular GPS systems, forms an integrated traffic analysis framework. Using AI, this vast amount of information is deciphered to forecast traffic trends and pinpoint areas prone to bottlenecks. Consequently, traffic light intervals can be modulated in real-time to mitigate jams and promote smoother vehicular movement. Additionally, predictive models, powered by ML, offer forward-thinking traffic control solutions instead of merely responsive ones.

Traffic Flow Optimization Techniques include ML models that are quite diverse in approache, encompassing regression, decision trees, and random forests, are tailored using past traffic records to foresee traffic tendencies. Leveraging these forecasts can guide modifications in traffic light timings and enhance road movement. By utilizing Reinforcement Learning, traffic light durations can be dynamically calibrated, drawing from the outcomes of eased bottlenecks and smoother road flow. Models for Traffic Simulation, commonly rooted in cellular automata or agent-centric designs, replicate varied traffic scenarios. This aids in experimenting with and honing signal duration strategies.

Fig 2. *Tethered drone as a "brain" of AI operations*

4 SYSTEM OF ENERGY-EFFICIENT DRONES WITH AI

In light of the energy-intensive tasks that AI performs on drones used for traffic monitoring, a significant challenge is emerging. AI's demands on the drone's batteries lead to reduced operational time and unpredictable mission outcomes. This issue becomes especially critical in scenarios involving traffic accidents or search and rescue (SAR) operations where human lives or the welfare of animals are at risk. Equally significant are the implications for preventing undesirable events, such as speeding and reckless driving in violation of traffic regulations.

In order to provide energy-efficient drones that use AL to perform tasks in traffic, the system with one drone that is permanently connected to the power supply was proposed.

This approach involves employing advanced deep learning algorithms that demand higher energy consumption for data processing at drone with uninterapted power supply. The goal is to expedite the development of algorithms that optimize energy usage by making real-time decisions on the drone's path, positioning, and engine utilization in varying weather conditions. Subsequently, the knowledge and patterns learned would be transferred to other, untethered drones, significantly reducing the time needed to establish optimal energy-efficient drone behaviors.

Using a tethered drone equipped with AI neural networks as a "knowledge center" to transfer knowledge (primarily related to optimizing energy consumption) to other drones is an innovative concept. The concept holds promise, especially for scenarios where UAVs must perform complex AI-driven tasks in environments where energy conservation is essential. By offloading energy-intensive AI data processing to the tethered drone, it essentially creates a "brain" for the drone swarm, allowing individual drones to be lighter and more energy efficient.

However, the success of such an approach largely depends on the effective application of communication and coordination protocols, the robustness of AI algorithms, and the system's resistance to potential failures or external threats. If these challenges can be successfully tackled, this approach holds the potential to provide a compelling means of optimizing drone operations, harmonizing the benefits of centralized processing with the flexibility of decentralized drone mobility. However, overcoming these demands a holistic strategy that integrates technological solutions with operational best practices, adherence to regulatory requirements, and an ongoing commitment to learning and adaptation. By proactively addressing potential issues, the concept of tethered drone "knowledge hubs" can be both feasible and effective.

The tethered drone serves as an initial testing platform for resource-intensive AI algorithms, allowing for optimization and validation. Once proven effective, these algorithms can be leveraged by untethered drones in similar missions, maximizing the impact of AI-driven traffic management without the constraints of a tethered power source.

Tethered drones equipped with power-hungry AI algorithms can be stationed on highways with high traffic volume and accident-prone areas. These drones can rapidly assess complex accident scenes, providing detailed live feeds and coordinating emergency response. After successful testing, the AI algorithms can be employed on untethered drones for incident management on other busy highway stretches.

Another use of tethered drones with advanced AI algorithms to manage traffic during large-scale events in stadiums or festivals where traffic patterns are dynamic and challenging. These drones can optimize traffic flow and crowd management efficiently. Once the algorithms are proven effective, they can be applied to untethered drones for similar event traffic control.

In order to enforce speed limits on highways known for accidents a tethered drone with high-power AI algorithms can be used. The drone can accurately detect speeding violations and provide evidence for law enforcement. After validation, the AI algorithms can be used by untethered drones to enforce speed limits in other accident-prone areas.

A complex and heavily congested intersection is excellent option to deploy a tethered drone (Fig. 2.) The drone uses AI algorithms to process extensive real-time traffic data and optimize traffic signal timings. These algorithms require significant computational power and can improve traffic flow dramatically. Once refined, they can be transferred to untethered drones to optimize signal timings at other challenging intersections.

In situations when there are works on the roads in progress and the traffic is rerouted to other bypassing roads, tethered drones that use powerfull AI algorithms are fast and efficient way to optimize rerouting and increase satisfaction of the end-users.

5 CONCLUSION

In this paper, an overview of the utilization of drones and artificial intelligence in traffic management is provided. To address the challenge of battery consumption when implementing AI algorithms for real-time traffic monitoring and management, a solution was proposed to achieve energy-efficient drone systems. Specifically, a tethered drone system was introduced, where one drone is connected to a power supply, providing significant processing power to execute demanding AI tasks. Furthermore, the knowledge and patterns acquired by this tethered drone are then transferred to other untethered drones for broader application.

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THE PROPER SELECTION OF ELECTRIC MOTORS FOR BRIDGE CRANES

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Abstract

This paper provides guidelines for the proper selection of electromotors for the drive mechanisms of bridge cranes. Initially, the advantages of analyzing the operation of the drive mechanism in a torque-speed diagram are highlighted (e.g., to determine the mechanical capabilities of the electromotor). In the main part of the paper, procedures for selecting the size of electromotors for the drive mechanisms of previously mentioned type of crane (based on required mechanical power, thermal capabilities, etc.) are presented, in accordance with the requirements of applicable European standards and other relevant technical regulations and recommendations.

***Keywords**: bridge cranes, electromotor selection, drive mechanism, European standards.*

1 INTRODUCTION

Today's approach to designing industrial cranes (common configurations and executions) dictates that a mechanical engineer-designer, when creating structural solutions for drive mechanisms, should select a greater number of components (electromotors, gearboxes, couplings, etc.) from the catalogs of specialized manufacturers. The proper selection of these components requires an understanding of the technological requirements of the working machine (in this case, the crane) and the drive system itself (e.g., for lifting loads or moving the crane/trolley), working environment conditions, various constraints, and the capabilities of individual assemblies to perform their intended function reliably, safely, and economically (while meeting the required parameters under given conditions). Improper selection of the electromotor during the design phase can lead to a variety of problems and operational interruptions for the crane.

Generally speaking, selecting the appropriate electromotor size includes determining its rated power. The first step covers the preliminary selection (according to type, performance, and size). The process of controlling the motor and its appropriate protection has to be defined in cooperation with electrical and mechatronics engineers. The second step, before the final selection of the electromotor from the manufacturer's catalog, additional calculation tests have to be made, such as heating the motor, possibilities of starting/breaking and mechanical overload. Due to the complexity of this issue, in the recent period, various international standards and technical references [4, 5, 7, 8] have been made that engineers have to accept while projecting cranes. Unfortunately, these questions haven't been further discussed in the national, professional, and scientific literature. This paper (due to its restricted scope) provides only the answers to the necessary questions regarding the proper selection of electromotors for the regular performance of drive mechanisms (for vertical and horizontal motions) of the bridge cranes because they are the most numerous in the industry. The given guidelines align with the previously mentioned European technical regulations and standards.

Before clarifying the selection and the verification of electromotors, there is an illustrated graphic presentation of survey of the whole drive mechanism operation, in the diagram torque T vs. angular velocity ω, with concise clarification. This approach is generally applicable (see papers [1, 2, 3]), and to a large degree, can contribute to the appropriate selection of electromotors.

2 SIGNIFICANCE OF THE OPERATION ANALYSIS OF DRIVE MECHANISMS IN THE DIAGRAM *T-ω*

Driving motors, working devices, and sometimes components for power transmission are on the whole, complex machines. The operation process of these machines is determined by a series of influences (mechanical, electrical, magnetic, thermal, chemical, etc.) which are mutually connected with more or less complex relations. These relations are described as analytical expressions (in a simple form if possible), or graphically, based on calculations or results of experiments. Mechanical engineers from the area of driving techniques, get more advantages from graphical displays i.e. mechanical characteristics than from analytical displays. The graphic presentation of mechanical characteristics is a line or a surface connecting all the points – possible pairs of force F (torque T) and velocity v (angular velocity ω or rpm n) values, given on the axes of a 2D (less often 3D – for the case of non-stiff kinematic relations) coordinate system. This approach (more thoroughly described in [3]) simplifies the understanding of the power transmission process and developing certain phases of movement, approximate determination of the duration of certain non-stationary phases of the drive system, etc. Surveying operations of the machine drive mechanisms (in case of bridge cranes), based on the movement of operating points in diagram T-ω, is shown in the example of one load hoisting drive with an asynchronous squirrel cage electromotor, gearbox, and mechanical brake, see Fig.1.

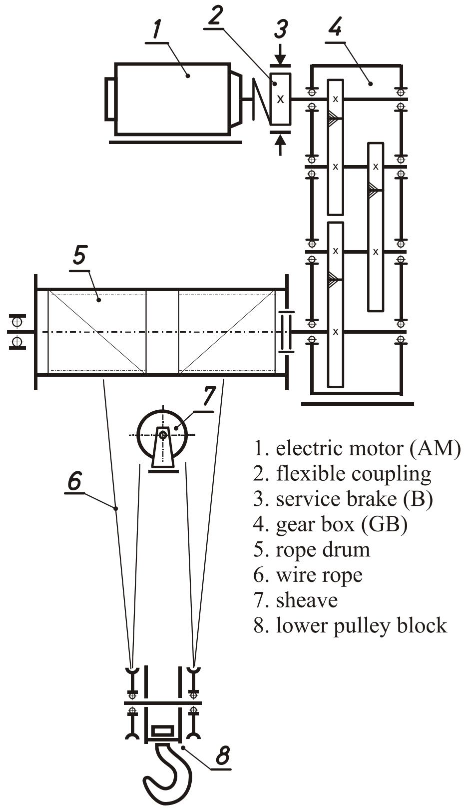

Fig. 1 *Scheme of a load hoisting mechanism*

The survey of the whole machine driving system operation demands the knowledge of state of all machine components in the regarded interval of operation. By putting mechanical characteristics of motor, working device, and also of power transmission components if needed, into the same diagram, a clear and well laid out survey of the whole machine in various operating regimes is enabled. Of course, the influence of velocity ratio through power transmission components has to be previously taken into account by reducing values of T, ω and masses in motion onto the same (arbitrary chosen) shaft, using the well known procedure based on the energy conservation law, [3].

Survey of machine operation based on the operating point motion through the T-ω diagram is presented on an example of a hoisting mechanism with AM, GB, B, and WD (load gravity force and losses), Fig. 2, [1]. For GB without mechanical characteristic, momentary state of AM, B, and WD is defined by the position of operating points (pairs of T and ω values) on their steady state mechanical characteristics.

Two parts of mechanical characteristic AM correspond to the two rotor rotation senses (load hoisting AM↑ and lowering AM↓). Load hoisting mechanisms are obligatorily equipped with mechanical brake(s) with given characteristic B. Braking is produced by friction (reactive) forces, so, the sign of braking torque is always opposite to the sign of velocity. Assuming the constant braking torque value (acceptable for an approximate consideration), characteristic B can be presented with a pair of straight lines in quadrants II and IV, parallel to ω-axis. By connecting them with a straight line along the T-axis, brake characteristic B is integrated. In a hoisting mechanism, brake B automatically starts in the moment when AM supply is cut-off, and vice-versa. Mechanical characteristic WD origins mostly from the load gravity force (potential force), so it can be presented with sufficient accuracy by the function T_{WD} = const. (independent of ω). In Fig. 2, it is shown as 2 parallel shifted parts in quadrants I and IV, with almost, but not quite the same values of T_{WD}, due to the influence of losses in the power transmission (friction etc.), added to the load gravity force, in quadrant I with sign +, and in IV quadrant with sign –, because the force corresponding to losses is a reactive force.

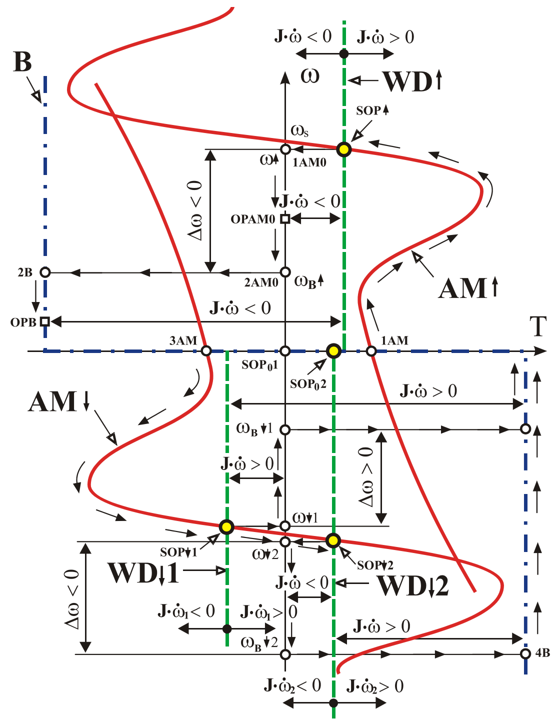

Fig. 2 *Survey of hoisting mechanism operation*

Hoisting starts at AM operating point 1AM on the T-axis. In that moment, the torque of AM T_{AM} is larger then the resistance torque of WD T_{WD}, positive difference of their values defines the inertial torque $T_{in} = J\cdot\varepsilon > 0$ (note: $\varepsilon = d\omega/dt = \acute{\omega}$), that "surplus" torque accelerates the mass J "upwards" (i.e. in the sense that corresponds to load hoisting), so the operating points of AM and WD (each along its characteristics), move synchronously upwards. Motion of operating points (i.e. system acceleration) continues as long as there exists "surplus" torque. In the crossing point of characteristics $T_{AM} = T_{WD}$, there exists no "surplus" torque, so $T_{in} = J\cdot\varepsilon = 0$, $\rightarrow \varepsilon = 0$, hoisting continues with ω = const, so the steady state operating point during hoisting SOP↑ is achieved.

The next rules can be defined on the basis of the described:

- when the operating point of AM is on the right side (in this arrangement of axes) of the operating point of WD, system accelerates, in the opposite case decelerates,
- intensity of acceleration/deceleration is proportional to the horizontal distance between operating points of AM and WD,
- steady state motion exists only when operating points of AM and WD are in the crossing point SOP (steady state operating point) of characteristics; they can leave SOP only if T_{AM} or T_{WD} changes its value (disturbance),

– if the position of SOP is stable, after any short-lasting disturbance both operating points return to SOP, in the opposite case they go away from SOP,
– operating points of AM and WD always tend to reach the crossing point of their characteristics.

Duration of the time period between the moments of AM supply cut-off and braking start is brake time delay. When AM supply is cut-off, AM operating point "jumps" horizontally in the point 1M0 on the ω-axis, which now plays the role of AM characteristic. Hoisting motion decelerates until the operating point reaches point 2M0, which corresponds to the change of angular velocity $\Delta\omega$ during brake time delay. Assuming that the brake momentarily develops full braking torque, operating point horizontally "jumps" in the point 2B on the brake characteristic, becoming the brake operating point. Eventually, steady state point $SOP_0 2$ corresponds to the motionless state of load hanging in the air, in case of nonselfbraking power transmission components.
Load lowering with the opposite sense of AM rotor rotation → AM↓ can be explained and surveyed in an analogous way. The diagram shows also characteristic WD↓1, corresponding to the selfbraking mechanism of power transmission. Steady state point $SOP_0 1$ corresponds to the grounded load.

3 THE SELECTION OF ELECTROMOTORS AND SPECIFIC REQUESTS ACCORDING TO [4]

When calculating and selecting motors for vertical movement (load hoisting) and horizontal movement (trolley traversing or crane traveling) the appropriate loads have to be specified based on EN 12001-2, with the value of dynamic factors ϕ_i = 1 and the partial safety factor γ_P = 1. Unless requested differently, in a calculation, the hoisted load should be equal to the rated capacity of the crane. In the case of outdoor cranes, the wind force should also be determined by EN 13001-2. Further considerations in the paper only relate to bridge cranes which operate in indoor spaces.

3.1 Required motor power and torque for vertical movement

The required stationary power of electromotor mechanisms for hoisting loads in [kW] is specified very easily:

$$P_{EM} = \frac{m_h \cdot g \cdot v_h}{1000 \cdot \eta_h}, \tag{1}$$

where:
m_h – mass of the hoist load, [kg];
g – acceleration due to gravity, [m/s^2];
v_h – lifting speed, [m/s];
η_h – total efficiency of hoisting mechanism, [–].

The mass of the hoist load m_h includes the masses of the payload m_Q and lifting attachments (for example, mass of the lower pulley block).

The maximum torque at the motor shaft ($T_{\max}$) shall be calculated by transforming the external load actions to a torque at the motor shaft, applying the maximum values of load actions. The load action due to acceleration of the motion may be omitted.
The possibility of starting the motor is evaluated based on the following requirement:

$$\frac{T_D}{T_{\max}} \geq k_{v\min}, \tag{2}$$

where:
T_D – design motor torque in [Nm] taken as the minimum torque developed by the motor and the drive system together during the starting period of the motion, see Fig. 3 (Note: The combined behaviour of the drive system and the motor shall be taken into account, when determining the torque);
$T_{\max}$ – maximum torque in [Nm] at the motor shaft resisting the movement;
$k_{v\min}$ – safety factor (see Tab. 1) , [–].

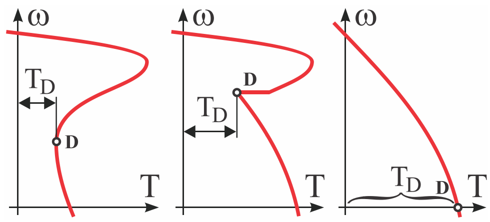

***Fig. 3** Torque T_D for different forms of torque curves*

Table 1 *Values of safety factor $k_{v\min}$*

Type of motor and drive	Squirrel cage motors: direct starting and drive	Squirrel cage motors: inverter drives	Slip ring motors	DC motors and drives
$k_{v\min}$	1,6	1,3	1,5	1,3

3.2 Required motor power and torque for horizontal movement

When determining the required motor power for trolley traversing and crane traveling that works in indoor spaces, it takes into consideration the total travel resistance (as a result of rolling resistance and bearings friction) as well as the influence of inertion (in the phase of acceleration of the trolley/crane). According to the rules, the crane runway is viewed as horizontal (the slope of the path of the moved mass is less than 5% in relation to the horizontal level). However, the tilted position of the rails should also be taken into consideration when determining the required power of the motor.

The total movement resistance of the steel wheel equipped with roller bearings of a trolley/crane on a flat surface of the steel rail head can be determined according to the following formula:

$$F_{tr} = F_w \cdot w_r, \tag{3}$$

where:
F_w – wheel force perpendicular to the running surface, [N];
w_r – rolling friction factor according to [4].

The value of the friction factor for the wheel/rail contact used in verifications when slipping/blocking of driving/braking wheels is also defined according to standard [4]. In case the crane is in an indoor space, the measures are adopted μ = 0,18 (clean environment) and μ = 0,14 (contaminated environment).

Inertial force F_{acc} operates during the acceleration of the trolley/crane and can be estimated based on the following relation:

$$F_{acc} = \alpha_{rot} \cdot m_{tr} \cdot a \,, \qquad (4)$$

where:

α_{rot} – the factor that takes into account the influence of the mass of rotating parts of drive mechanisms (for preliminary calculations, the value is recommended to be $\alpha_{rot} \approx 1{,}2$);

m_{tr} – the mass which has a translational movement (mass of a trolley or crane), [kg];

a – acceleration of trolley/crane (the common values are $a = 0{,}2 \div 0{,}4$ m/s^2 for trolley and bridge crane which is intended for hoisting load using a hook, however, if a isn't specified, the recommended acceleration time is $t_{acc} \approx 5$ s).

According to the defined translational speed of the crane v_{tC} i.e. trolley v_{tT}) and the value of the total efficiency of drive mechanism η_t it is easy to determine the required power for horizontal movement. However, it should be taken into account that the motor power for horizontal movement, as a rule, is not determined by the most adverse conditions (because they don't last long and the electromotors have the possibility of significant short-term overload), but by mediocre performance conditions of the trolley/crane.

In the case of an bridge four-wheel crane without crane wheels coupling by shaft, it can be assumed that the power of two motors is required to move the crane (one motor i.e. drive wheel on each end carriage) equals approximately 2/3 of the total power required for moving the crane. Unless the designer considers this recommendation, there can be unwanted occurances in the later exploitation of the crane (slippage of the driven wheel on the less loaded side of the crane, which is driven by motors without inverter drives), when the trolley is on the other side of the main girders.

In order to guarantee the starting of the motion to the intended direction, at a reasonable acceleration and under specified wind conditions, the sum torque developed by the motors shall satisfy the condition of Eq. (5).

For reaching the specified acceleration in average wind conditions, the drive system shall satisfy the following requirement:

$$\frac{T_D}{T_{tr} + T_{acc} + T_{w1} + T_{inc}} \geq k_{h\min} \,, \qquad (5)$$

where:

T_D – sum of the design motor torques, taken as the minimum torque developed by the motor and the drive system together during the starting period of the motion, see Fig. 3 (Note: The combined behaviour of the drive system and the motor shall be taken into account, when determining the torque);

T_{tr} – torque at the motor shaft due travel resistance;

T_{acc} – torque at the motor shaft due to acceleration;

T_{w1} – torque at the motor shaft due to wind force during controlled movement (according to EN 13001-2);

T_{inc} – torque at the motor shaft due to inclination of the path of moved masses;

$k_{h\min}$ – safety factor ($k_{h\min}$ = 1,1 for all types of drive systems).

Given due consideration that a crane is in an indoor space (and the rails are in an ideal horizontal position), in Eq. 5, T_{w1} = 0 and T_{inc} = 0. The condition that should be fulfilled, when the maximum force of wind on the crane is taken into account (based on EN 13001-2) which operates outdoors, is specifically emphasized in standard [4].

3.3 Specific requests and motor verifications

One of the main characteristics of the electromotor drive mechanisms of cranes is intermittent work in cycles that repeat more or less regularly. The intensity of the motor duty is described through a cyclic duration factor *ED*. It is specified for a periodic, intermittent motor duty and for a period of no longer than 10 min. In the absence of more accurate data on the duration of the operations that make up the work cycle of the questioned drive, when defining *ED*, the designer can rely on the recommendations stated in [8]. On behalf of these recommendations for drive mechanisms of workshop bridge crane, the general purpose fits that *ED* = (25 ÷ 40)%. If more accurate and sufficiently reliable data on the duration of operations and work cycles are available, the *ED* factor in percentages is calculated according to the following expression:

$$ED = \frac{t_R}{t_R + t_O} \cdot 100 \,, \qquad (6)$$

where:

t_R – running time of the motor within a 10 min period, [min];

t_O – idle time of the motor within a 10 min period, [min].

The factor *ED* is used for thermal power rating of asynchronous squirrel cage electromotors in S3-type intermittent duty (duty types according to [6]). Besides these motors, slip-ring motors, determined by S4- and S5-type intermittent duty, are used as a priority for vertical movement (although nowadays, they are considered to be a dated solution with restricted possibilities of controlling).

In checking the thermal capabilities of the motor, it is also very important to determine the mean equivalent torque and power. The mean equivalent power is a power comparable to the thermal capacity of a motor. The power is derived through motor torques due to external loadings. The mean equivalent torque shall be determined as a function of the affecting torques during the working cycles. When arranging a work cycle into different phases such as acceleration, deceleration and steady movement, the number of which is n, the mean equivalent torque T_{med} in [Nm] shall be calculated using the following formula:

$$T_{med} = \sqrt{\frac{T_1^2 \cdot t_1 + T_2^2 \cdot t_2 + \ldots + T_n^2 \cdot t_n}{t_1 + t_2 + \ldots + t_n}} \,, \qquad (7)$$

where: T_1, T_2, T_n in [Nm] the motor torques affecting in different phases of a work cycle; t_1, t_2, t_3 in [s] the duration times of the torques affecting at the motor shaft within a work cycle (idle times, when both the motor speed and torque are zero, are not taken into account).

If the crane can perform several work cycles in a 10 min period, a variety of hoist loads may be taken into account so that the mean equivalent torque is calculated over a total period of approximately 10 min. If an average work cycle takes 10 min or longer – including the idle times – the torques shall be calculated applying the rated load only, without consideration of variety in magnitude of loads.

In the case of indoor crane, for the calculation of the torques in Eq. (7), the true characteristics of work cycles shall be taken into account with consideration of the following: loaded and return phases of a work cycle; lifting and lowering of the load; acceleration and deceleration loadings; mechanical efficiency, both increasing and decreasing the motor torque.

The mean equivalent power P_{med} shall be calculated using the formula $P_{med} = T_{med} \cdot \omega$, where ω in [s^{-1}] the nominal angular speed of motor.

The thermal power rating of the motor shall meet the following requirement:

$$k \cdot P_{mot} \geq P_{med} \,, \qquad (8)$$

where:

P_{mot} – the rated power of the motor in a standardized duty class S1, S2 or S3 in [kW], applicable for the work cycles used in calculating T_{med} and P_{med} (in general specified for ambient temperature 40 °C and altitude 1000 m above sea level);

k – the power correction factor to take into account decreased cooling speed of motors in high ambient temperatures and high altitudes (motor insulation class F and integrated cooling in the motor), see Fig. 4.

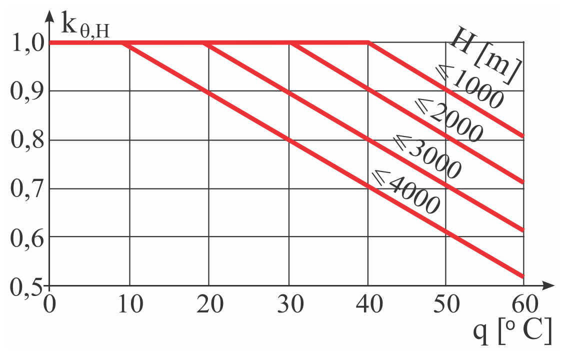

Fig. 4 *Power correction factor k (k_Θ for temperature and k_H for altitude above sea level)*

In the thermal calculation of the motor, it is necessary to take into account the relevant load combinations according to EN 13001-2, as well as the specific provisions of standard [4, 7].

4 CONCLUSIONS

By examining the available national and international literature, there are some practical questions and considerations that are incomplete regarding the issue of selecting electromotors for drive mechanisms of industrial cranes. In comparison with earlier practice, (primarily in the field of mechanical engineering), a more modern and thorough approach of the crane designer is necessary, bearing in mind the clearly defined requirements in European norms [4, 5, 7] and recommendations stated in [8]. Many relevant provisions mentioned here are correspondent and weren't separately commented on. Certain specificities regarding the selection of electromotors were given in other European norms that refer to the remaining types of cranes.

In the end, the emphasis is on the fulfillment of the concisely presented requirements in this work that also guarantees compliance with the Machinery Directive requirements.

At the same time, the crane designer has to face the fact that the vast majority of earlier national standards (which the design practice in this area was based on for decades) have already been withdrawn, and are, therefore, also invalid. From this, it follows that the design of electromotor drive systems, or all other structural units of new cranes, should be based on the newly adopted harmonized standards, e.g. [4] has been in force for about ten years!

This is particularly important for countries such as the Republic of Serbia, primarily to raise the quality of domestic industry products to a higher level, mainly to incorporate them into the technical regulations of the countries, for example, EU members, whose markets are our companies trying to enter. It should be taken into consideration that if the manufacturer (of cranes) does not apply the relevant, valid European standards, harmonized standards, in the design, it must experimentally, computationally, or through computer simulations prove (to the competent authority) that all solutions applied on the machine provide at least the same or higher level of reliability, safety, and health when working with that machine.

According to the above, it is necessary to recognize the importance of educational promotion (by standardization bodies, technical universities, chamber of engineers, etc.) of current contents of the new technical regulations, as well as modern scientific knowledge that can contribute to the practical work of engineers-designers.

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OPTIMAL DESIGN OF THE BATTENED BUILT-UP COLUMN OF THE CRANE RUNWAY BEAM

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Abstract

This study presents the analysis and the optimal design of the battened built-up column of the crane runway beam. One economic-inspired algorithm, called Supply-Demand-Based Optimization (SDO), was used for the optimization procedure. The objective function is the overall weight of the battened built-up column, which consists of two chords (the cold-formed U-profiles) and batten plates. This research uses all necessary stability and strength criteria (according to Serbian standards) and geometrical recommendations as the constraint functions. The justification for applying this method to the considered problem was confirmed by comparing the results with results from the published research. Achieved savings in the built-up column's weight are between 12,55% and 20,42%, depending on the number of batten plates and type of structural steel.

***Keywords**: built-up column, stability, channel section, metaheuristic, supply-demand-based optimization.*

1 INTRODUCTION

When standard steel profiles cannot withstand large compressive forces, engineers design built-up columns. It is often the case with the columns for the cranes' runway beams. A built-up column usually consists of two or more standard rolled steel profiles, acting like stand-alone chords, interconnected by lacing or batten plates. Stand-alone chords are often C, U, I or L steel profiles, although some other shapes or combinations can exist.

Structural analysis for this type of structure is commonly conducted in some finite element method (FEM) software using various types of finite elements. ABAQUS was used in [1], where a battened built-up column with two chords (web-stiffened C-profiles), was subjected to the eccentric load in a positive and negative direction. The results complied with the experiment, so applying the mentioned software was justified. Furthermore, the application of the ANSYS program was presented through a parametric study. The truss supporting structure was analyzed using ANSYS in the paper [2], where the main structure components were battened built-up columns with two chords (C-profiles). Steel and an aluminium alloy were considered as materials. Research results were compared to analytical ones obtained from Eurocode, and certain conclusions and directives were derived for the design of this type of structure.

The manner of combining the FEM analysis results with the ones obtained from some design code is present in many investigations, [3]-[7]. To determine the fastest and the most straightforward calculation of the axial capacity of the battened built-up column with two chords, the comparison of different methods was presented in [3], using Eurocode and Polish standards. Also, the FEM models with beam and plate finite elements were established and verified. The results were compared with the ones available in the literature. A battened built-up column with two chords made of C-profiles was considered in the paper [4], with different column lengths and distances between the chords. The number of batten plates was studied through FEM. The results were compared with the ones obtained from Eurocode and North-American standards. Applying FEM, a parametric study of a battened built-up column with two chords made of C-profiles was considered in [5] to investigate its nonlinear structural behaviour based on changeable global slenderness of the column, slenderness of the batten plates and yield strength. Obtained results help within the assessment of FEM results for this type of structure concerning the North-American and Eurocode standards. The paper [6] studied the influence of chord compactness and slenderness of battened built-up columns with two chords made of U-profiles by ABAQUS software. Varying parameters were width/thickness ratio, overall column slenderness ratio, and spacing of chords. The results were compared with the ones obtained from Eurocode and Norh-American standards. Based on reliability verification, some recommendations were given for the design of this type of supporting structure. Similar to the previous, the paper [7] identified the relative slendernesses of the chords in the steel battened built-up columns, which were in good agreement with North-American and Eurocode standards. Furthermore, new design rules were proposed and verified through reliability analysis.

Besides FEM, theoretical research and optimization of built-up columns are frequent, [8]-[11]. The theoretical analysis of the elastic stability of laced and battened built-up columns with two chords was done in the paper [8]. Similar to the previous, a theoretical study of the stability of battened built-up columns with two chords and the frames was conducted in [9]. The optimization of the number and dimensions of batten plates in built-up columns with two chords (for two design solutions) made of standard U-profiles was done in the paper [10]. It was monitored how the variables' optimum values were changing with the increase of the compression force. EA code was used through MS EXCEL software as an optimization method. Similar to the previous research, the weight of the battened built-up column with two chords was optimized, where the chords of the built-up column were welded I-profiles, [11]. This time, besides the number of batten plates and their dimensions, the optimization included the geometrical parameters of the welded I-profiles' plates. GRG2 code was used through MS EXCEL software as an optimization method. In two previous investigations conducted by EA and GRG2 code, it was possible to determine an optimal number of the batten plates since both codes can treat the variables as integers, which was very important.

This research aims to decrease the weight of the crane runway beam column, which has two U-profiles acting as the chords.

The main goal in this research is to justify the usage of U-profiles made by bending the plates to the exact dimensions, which are the optimization parameters, instead of standard rolled U-profiles. In addition, the batten plates' dimensions are also optimized, where their number is the input parameter. The number of batten plates and the material of the crane runway beam column are varied. Applying the proposed solution of a battened built-up column is justified through one example.

Since the application of metaheuristic algorithms increases in a variety of engineering problems, both single-objective and multi-objective, a new-generation metaheuristic algorithm, the Supply-Demand-Based Optimization (SDO) algorithm, [12] and [13], is chosen for this research.

2 THE OPTIMIZATION PROBLEM

The optimization problem in this paper is the weight minimization of the battened built-up column of the crane runway beam (Fig. 1).

Fig. 1 shows the design of the battened built-up column (crane runway column). The distance between the batten plates is designated as a, while the *A-A* section view depicts the cross-section and positioning of the chords (U-profiles).

The main goal of this research is to use U-profiles made by bending steel plates with the thickness of t=6mm instead of standard rolled U-profiles to gain material savings while satisfying all necessary criteria. Furthermore, it will be shown how the number of batten plates and material type selection impact the overall weight of the battened built-up column.

The nature of the load for this column type imposes numerous criteria that must be met concerning overall stability, partial stability, and strength of the column elements and welded connections. Also, some geometric and design recommendations must be taken into account, according to [14].

The results will be compared to those from the paper [10], through a column design example to justify the application of the proposed optimization model.

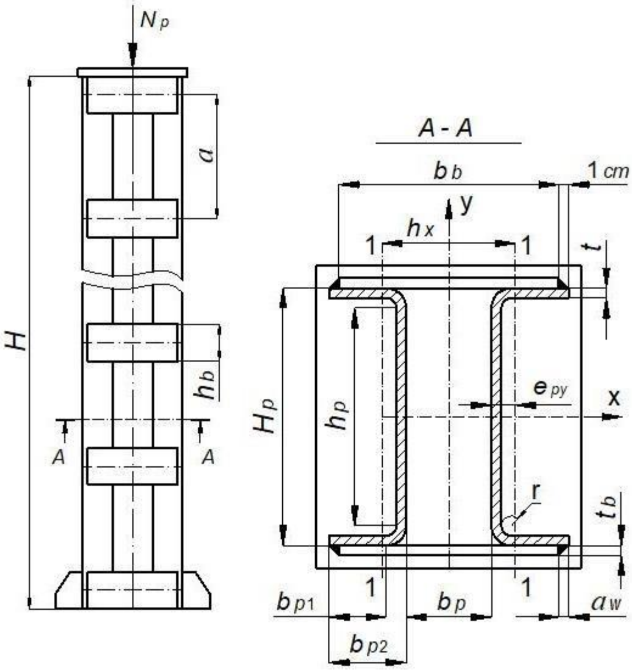

Fig. 1 *The structure of the battened built-up column with two chords and the view A-A (cross-sectional area)*

3 THE OBJECTIVE FUNCTION AND CONSTRAINT FUNCTIONS

The objective function is the total weight of the buttened built-up column (Fig. 1). The column consists of two chords, i.e. U-profiles, connected by welded batten plates, where the thickness of the fillet welds is a_w.

Fig. 1 shows the variables and all significant geometric parameters necessary for the analysis and optimization procedure.

The variables (x) in the optimization are:

$x_1 = b_{p1}$, $x_2 = \lambda$, $x_3 = h_b$, $x_4 = t_b$, $x_5 = a_w$,

where b_{p1} is the width of U-profile (from the radius r, Fig. 1), λ is a slenderness of the built-up column, h_b is the batten plate height (Fig. 1), t_b is the batten plate thickness (Fig. 1), and a_w is the weld thickness (Fig. 1).

The input parameters for the optimization are:

N_p, n, H, α_1, α_2, β_1, β_2, ν_1, r, ρ, R_e, λ_v, E,

where N_p is the compressive force (Fig. 1), n is the number of the batten plates, H is the column height (Fig. 1), α_1, α_2 are the coefficients, [14], β_1, β_2 are the buckling coefficients, ν_1=1,5 is load case 1 factored load coefficient, [14], r=6mm is the inner radius of U-profile (Fig. 1), ρ is the material density, R_e is the yield strength, [14], λ_v is the yield slenderness (depends on R_e), [14], and E is the elastic modulus, [14].

The total weight of the battened built-up column with two chords (M_{co}), i.e. the objective function $f(x)$, is defined as follows:

$$f(x) = M_{co} = 2\rho\left(A_p \cdot H + n \cdot x_3 \cdot x_4 \cdot b_b\right) \quad (1)$$

$$A_p = \left[\left(h_p + 2x_1\right) + \pi(2r + t)/2\right] \cdot t \quad (2)$$

$$h_p = H_p - 2(r + t) \quad (3)$$

$$H_p = (\beta_1 \cdot H)/(\alpha_1 \cdot x_2) \quad (4)$$

$$b_b = b_p + 2(b_{p2} - 1) \quad (5)$$

$$b_p = (\beta_2 \cdot H)/(\alpha_2 \cdot x_2) \quad (6)$$

$$b_{p2} = x_1 + r + t \quad (7)$$

where A_p is the area of U-profile (Fig. 1), H_p is the height of U-profile (Fig. 1), h_p is the inner height of U-profile (Fig. 1), b_{p2} is the width of U-profile (Fig. 1), b_p is the distance between the chords (Fig. 1), and b_b is the batten plate width (Fig. 1).

Noticeably, the variable x_5 is not present in the objective function. It is to be defined within the criterion of welded connections' strength.

The geometric characteristics of the U-profile are: I_{py} – the principal moment of inertia about y-axis, i_{px} – the radius of gyration about x-axis, i_{py} – the radius of gyration about y-axis, e_{py} – the position of the centre of gravity about y-axis (Fig. 1), and W_{py} – the section moduli about y-axis. These characteristics are present in the analysis and are calculated by well-known relations.

The battened built-up column must meet the criteria related to global stability, stability and strength checks of its segments, welded connections and some geometric and design recommendations. The majority of the criteria herein will be introduced as the constraint functions, while some will act as the limits of the variables (lower and upper bounds).

The constraint functions for the criterion of the global stability of the battened built-up column with two chords, according to [14], have the form:

$$g_1 = \nu_1 N_p - N_{EQ} \leq 0 \quad (8)$$

$$g_2 = a - 50 i_{py} \leq 0 \quad (9)$$

$$g_3 = \lambda_y - x_2 \leq 0 \quad (10)$$

where:

$$N_{EQ} = 2\pi^2 \cdot E \cdot A_p / {\lambda_{yi}}^2 \quad (11)$$

$$\lambda_{yi} = \sqrt{{\lambda_y}^2 + {\lambda_1}^2} \quad (12)$$

$$\lambda_1 = a / i_{py} \quad (13)$$

$$a = (H - x_3)/(n - 1) \quad (14)$$

$$\lambda_y = (\beta_2 \cdot H)/i_y \quad (15)$$

$$i_y = \sqrt{I_y/(2A_p)} \quad (16)$$

$$I_y = 2[I_{py} + A_p \cdot (h_x/2)^2] \quad (17)$$

$$h_x = b_p + 2e_{py} \quad (18)$$

where N_{EQ} is the critical compressive force, I_y is the principal moment of inertia of the battened built-up column cross-section about y-axis, i_y is the radius of gyration of the battened built-up column cross-section about y-axis, λ_{yi} is the slenderness of the battened built-up column about y-axis, λ_y is the slenderness of the chord (U-profile) about y-axis, λ_1 is the slenderness of the chord about 1-axis (Fig. 1), h_x is the axial distance between the chords (Fig. 1), and a is the axial distance between the batten plates (Fig. 1).

The constraint functions for the criterion of stability of the battened built-up column with two chords about the material axis (x-axis), according to [14], have the form:

$$g_4 = \sigma_N - \chi_{im} \cdot \sigma_d \leq 0 \quad (19)$$

$$g_5 = \lambda_{ix} - x_2 \leq 0 \quad (20)$$

where:

$$\sigma_N = N_p/(2A_p) \quad (21)$$

$$\sigma_d = R_e/\nu_1 \quad (22)$$

$$\chi_{im} = f(\lambda_{ix}/\lambda_v) \quad (23)$$

$$\lambda_{ix} = (\beta_1 \cdot H)/i_{px} \quad (24)$$

where σ_N is the buckling stress for the battened built-up column, σ_d is the critical stress, χ_{im} is the reduction factor for the battened built-up column about the material-axis (x-axis), and λ_{ix} is the slenderness of the chord (U-profile) about x-axis.

The constraint function for the criterion of stability of the battened built-up column with two chords about the non-material axis (y-axis), according to [14], has the form:

$$g_6 = \sigma_N - \chi_{in} \cdot \sigma_d \leq 0 \quad (25)$$

where:

$$\chi_{in} = f(\lambda_{yi}/\lambda_v) \quad (26)$$

where χ_{in} is the reduction factor for the battened built-up column about the non-material-axis (y-axis).

The constraint function for the criterion of stability of the battened built-up column with two chords about 1-axis, according to [14], has the form:

$$g_7 = \sigma_{N1} - \chi \cdot \sigma_d \leq 0 \quad (27)$$

where:

$$\sigma_{N1} = N_{p1}/A_p \quad (28)$$

$$N_{p1} = N_p/2 + M_y \cdot A_p \cdot h_x/(2I_y) \quad (29)$$

$$M_y = N_p \cdot w_o/[1 - \nu_1 N_p \cdot {\lambda_{yi}}^2/(2A_p \cdot R_e)] \quad (30)$$

$$\chi = f(\lambda_1/\lambda_v) \quad (31)$$

where σ_{N1} is the buckling stress for the chord (U-profile) of the battened built-up column about 1-axis, χ is the reduction factor for the chord of the battened built-up column about 1-axis, N_{p1} is the compressive force acting on the chord of the battened built-up column, M_y is the bending moment acting on the battened built-up column, and w_o=H/500 is the initial geometric imperfection of the battened built-up column, [14].

The constraint function for the criterion of the strength of the chord (U-profile) of the battened built-up column with two chords (at the end field), according to [14], has the form:

$$g_8 = \sigma_m - \sigma_d \leq 0 \tag{32}$$

where:

$$\sigma_m = N_p/(2A_p) + Q_m \cdot a/(4W_{py}) \tag{33}$$

$$Q_m = (\pi/H) \cdot N_p \cdot w_o/(1 - v_1 N_p/N_{EQ}) \tag{34}$$

where σ_m is the maximum stress for the chord of the battened built-up column and Q_m is the transverse force of the chord of the battened built-up column.

The constraint function for the criterion of the strength of the batten plate of the battened built-up column with two chords, according to [14], has the form:

$$g_9 = \sigma_{bm} - \sigma_d \leq 0 \tag{35}$$

where:

$$\sigma_{bm} = 3Q_m \cdot a/(2 \cdot x_4 \cdot x_3{}^2) \tag{36}$$

where σ_{bmx} is the maximum stress for the batten plate of the battened built-up column.

The constraint functions for the criterion of the strength of the fillet weld connection (Fig. 2), according to [14], have the form:

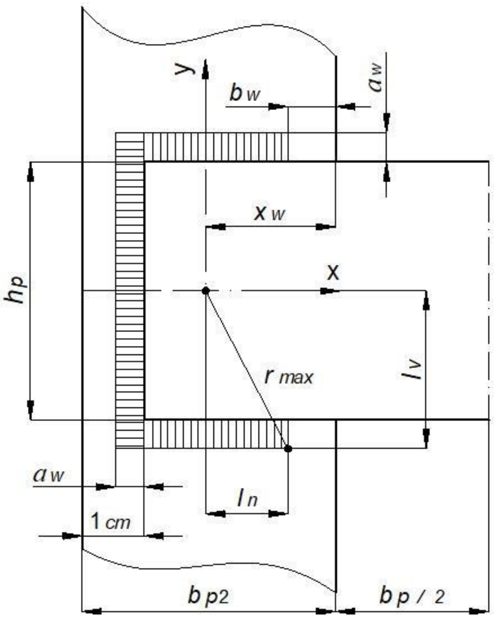

Fig. 2 *The fillet weld connection*

$$g_{10} = \sigma_w - 0{,}75 \cdot \sigma_d \leq 0 \tag{37}$$

$$g_{11} = x_5 - a_{wd} \leq 0 \tag{38}$$

where:

$$\sigma_w = \sqrt{(V_{nt} + V_n)^2 + V_v{}^2} \tag{39}$$

$$V_{nt} = T/[2(x_3 + 2x_5) \cdot x_5] \tag{40}$$

$$T = Q_m \cdot a/h_x \tag{41}$$

$$V_n = T_o \cdot l_n/r_{max} \tag{42}$$

$$V_v = T_o \cdot l_v/r_{max} \tag{43}$$

$$T_o = M_w \cdot r_{max}/I_{ow} \tag{44}$$

$$l_n = x_w - b_w \tag{45}$$

$$l_v = h_p/2 + x_5 \tag{46}$$

$$r_{max} = \sqrt{l_n{}^2 + l_v{}^2} \tag{47}$$

$$b_w = x_5 + r + t \tag{48}$$

$$M_w = T \cdot (x_w + 0{,}5 \cdot b_p)/2 \tag{49}$$

$$a_{wd} = 0{,}7 \cdot min(t,\ x_4) \tag{50}$$

where σ_w is the maximum stress of the fillet weld connection (Fig. 2), a_{wd} is the permisible weld thickness, V_{nt} is the transverse stress component, V_n is the transverse stress component, V_v is the longitudinal stress component, T is the transverse force, T_o is the torsional stress, M_w is the torsion, I_{ow} is the polar moment of inertia of the fillet weld conection (Fig. 2), x_w is the position of the centre of gravity of the fillet weld conection (Fig. 2), and b_w, r_{max}, l_n, l_v are weld dimensions (Fig. 2). The constraint functions related to the geometric and design recommendations, according to [14], are:

$$g_{12} = 0{,}5 \cdot b_p - x_3 \leq 0 \tag{51}$$

$$g_{13} = x_3 - 0{,}7 \cdot b_p \leq 0 \tag{52}$$

$$g_{14} = x_3/30 - x_4 \leq 0 \tag{53}$$

$$g_{15} = b_p - 60 \leq 0 \tag{54}$$

4 THE OPTIMIZATION RESULTS AND DISCUSSION

The optimization was conducted using the original SDO code in MATLAB software, [13].

Supply-Demand-Based Optimization (SDO) is a novel metaheuristic algorithm inspired by the supply-demand mechanism in economics, which mimics both the demand relation of consumers and the supply relation of producers, [12]. The paper [12] gives a detailed description of this algorithm and many application examples in engineering, showing its solution's high accuracy, convergence rate, and efficiency compared to many considered algorithms.

The optimization procedure is applied to one column example, based on the paper [10], and the results from both researches were compared.

The column height is H=5m, the compression force at the top is N_p=400kN and the column material is S235 (R_e=23,5kN/cm^2, ρ=7850kg/m^3, and E=21000kN/cm^2). Other input parameters are: α_1=0,41, α_2=0,52 and β_1=1, β_2=2. The optimization was done for different numbers of batten sheets, for n=8 (Case 1) and n=7 (Case 2).

The control parameters of the SDO algorithm, for all cases are: N_{pop}=100 – the population size (the market size) and $Max,iter$=800 – the maximum number of iterations.

Bound values of variables are: $3{,}5 \le b_{p1} \le 20$, $60 \le \lambda \le 80$, $10 \le h_b \le 28$, $0{,}6 \le t_b \le 1{,}2$, $0{,}3 \le a_w \le 0{,}7$.

The objective function is defined by (1) and constraint functions are defined by (8)-(10), (19), (20), (25), (27), (32), (35), (37), (38), and (51)-(54). Table 1 shows optimal parameters and the time of the optimization process for Case 1 and Case 2, respectively.

Table 1 The optimization results for Case 1 and Case 2

Case	b_{p1} (cm)	λ (-)	h_b (cm)	t_b (cm)	a_w (cm)	time (s)
1	7,34	76,13	12,5	0,6	0,32	24,22
2	7,34	75,59	12,5	0,6	0,39	20,39

Table 2 shows optimal geometric parameters, column weight and savings in material for Case 1 and Case 2, respectively.

Table 2 Optimal geometric parameters, weight of the column and savings in material for Case 1 and Case 2

Case	$b_{p1,o}$ (cm)	$H_{p,o}$ (cm)	$b_{b,o}$ (cm)	$h_{b,o}$ (cm)	$M_{co,o}$ (cm^2)	Saving (%)
1	7,4	17,0	40,2	12,5	189,66	12,23
2	7,4	17,0	40,2	12,5	184,93	14,42

As can be seen in Table 2, the optimum weight is smaller for n=7 (Case 2) compared to Case 1 (n=8), which is expected, as shown in the paper [10], using the EA method. Index o designates optimal values.

The following figures (Figs. 3 and 4) show the convergence graphs for Case 1 and Case 2, respectively.

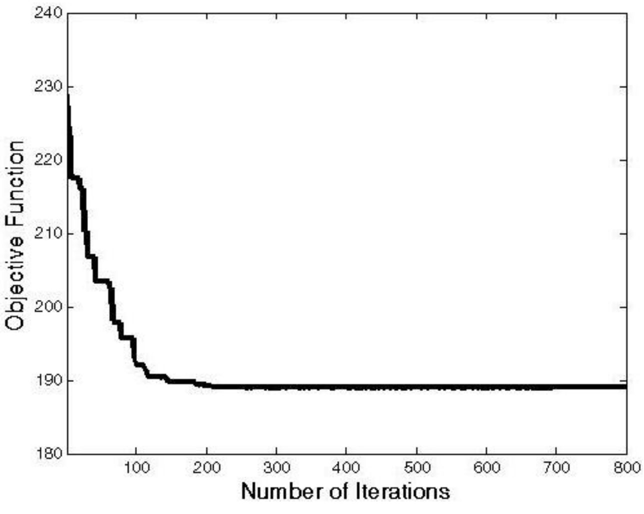

Fig. 3 *The convergence graph for Case 1*

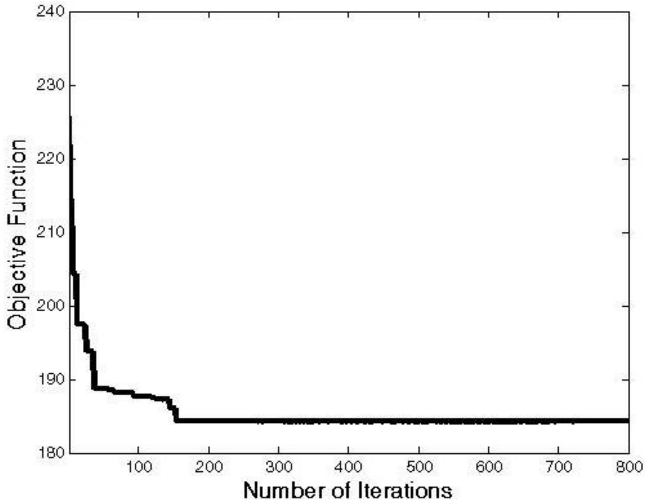

Fig. 4 *The convergence graph for Case 2*

Further on, the material of the column elements was changed for the case with n=7, where S275 (Case 3) and S355 (Case 4) were applied with their yield strengths R_e=27,5kN/cm^2 and R_e=35,5kN/cm^2, respectively.

Table 3 shows optimal parameters and the time of the optimization process for Case 3 and Case 4, respectively.

Table 3 The optimization results for Case 3 and Case 4

Case	b_{p1} (cm)	λ (-)	h_b (cm)	t_b (cm)	a_w (cm)	time (s)
3	6,48	76,21	12,5	0,6	0,36	20,41
4	6,84	80,00	12,0	0,6	0,37	20,74

Based on Tables 1 and 3, it is noticeable that the optimization time is almost the same, except for Case 1.

Table 4 shows rounded values of geometric parameters, column weight and savings in material for Case 3 and Case 4, respectively.

Table 4 Optimal geometric parameters, weight of the column and savings in material for Case 3 and Case 4

Case	$b_{p1,o}$ (cm)	$H_{p,o}$ (cm)	$b_{b,o}$ (cm)	$h_{b,o}$ (cm)	$M_{co,o}$ (cm^2)	Saving (%)
3	6,5	17,0	38,4	12,5	174,96	19,03
4	6,9	16,0	38,2	12,0	172,60	20,13

The following figures (Figs. 5 and 6) show the convergence graphs for Case 3 and Case 4, respectively.

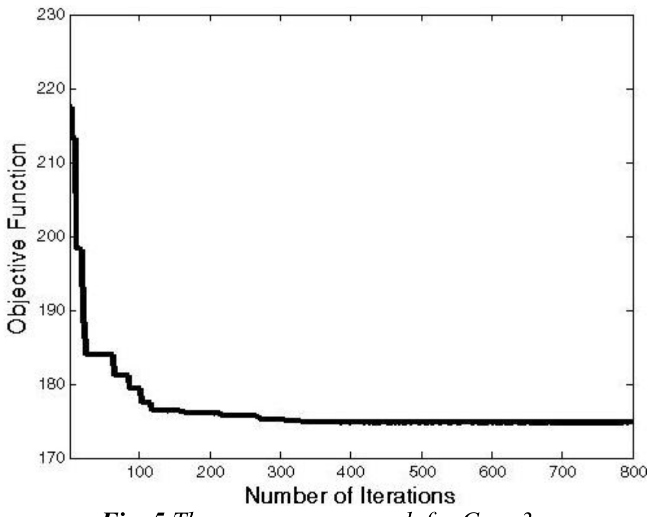

Fig. 5 *The convergence graph for Case 3*

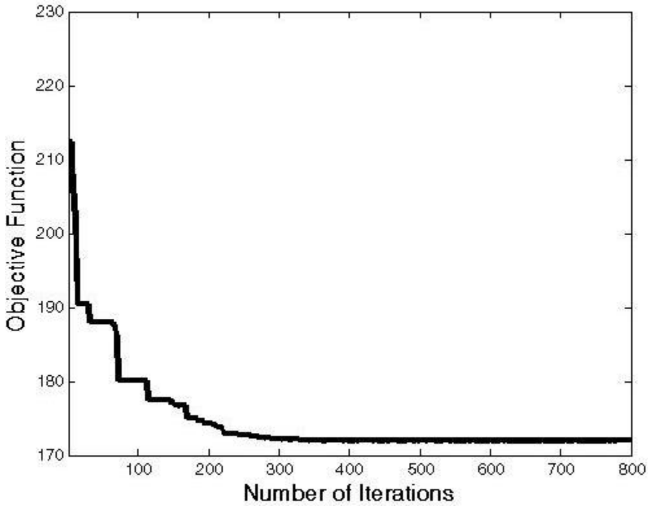

Fig. 6 *The convergence graph for Case 4*

In all the cases, material savings were achieved compared to [10], where standard rolled U-profiles were used as the chords.

Also, in all the cases, the optimal weld thickness (rounded value) is $a_{w,o}$=4mm, and plate thickness is $t_{b,o}$=6mm.

Based on Tables 2 and 4, it is noticeable that the material change decreases the column weight, especially when changing from S235 (Case 2) to S275 (Case 3).

5 CONCLUSIONS

This research analyses and optimizes the battened built-up column with two chords. Supply-Demand-Based Optimization (SDO) metaheuristic algorithm was used for the optimization process. The objective function is the weight of the crane runway beam's column (consists of two chords and batten plates). All necessary stability and strength criteria (strength of chords, batten plates and the welded connections), and some geometric and design are constraint functions. The results were compared with the ones from [10] through an example of a crane runway column.

In this research, savings in the material range from 12,23% to 20,13% (Tables 2 and 4), depending on the number of batten plates and type of structural steel. It was shown how using cold-formed U-profiles as the column chords (instead of standard rolled U-profiles) gained material savings in overall weight. This research justifies applying the proposed design solution with non-standard profiles and the employed optimization method.

The applied optimization algorithm relatively quickly achieved the optimal solution for this complex engineering problem (Tables 1 and 3), reaching the optimal solution in less than 500 iterations (convergence graphs, Figs. 3-6).

Further research could include different shapes for the column chords, variations of batten plates number, increase of the compression force, change of the material (chords and batten plates), and the influence of connection type between the chords and the batten plates. In addition, many new-generation algorithms can be tested to identify the most convenient one for this type of engineering problem.

ACKNOWLEDGMENT

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MULTIPLE OPTIMISATION ALGORITHM COMPARISON ON THE HEAVY-WEIGHT LOADING RAMP MECHANISM OPTIMISATION PROBLEM

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Abstract

Several metaheuristic optimisation algorithms were used and compared to obtain an optimal solution for the geometric parameters of a mechanism used for a heavy-weight loading ramp. The optimisation goal was to reduce the force in the hydraulic cylinder to start the ramp, i.e. to lower and raise it. For the optimisation process, a mathematical model that describes the movement of the mechanism members was established, and the dimensions of the corresponding members of the mechanism were determined, as well as the positions of the characteristic points of the mechanism, which enables the most negligible force in the hydraulic cylinder used to start the ramp. A comparative analysis of the results obtained by different algorithms was done.

Keywords: *Optimisation algorithms, loading ramp, comparative analysis, mechanism design, metaheuristic approach*

1 INTRODUCTION

Several solutions can be found for a specific problem or purpose that will fulfil specific requirements to a greater or lesser extent. Apart from whether a solution will meet particular needs, other criteria can be considered when choosing it.

Nowadays, the overall price of the solution plays a big, and very often decisive, role in this choice. In mechanical engineering, as well as in other areas of engineering, the price of a machine or device mainly depends on the amount of material used for its production and the price of the components installed in it. By reducing these amounts of material and installing smaller components, the price of the entire device, i.e. construction, will be proportionally reduced.

This paper discusses the mechanism for raising and lowering the ramp used to load heavy vehicles onto a trailer for their transport. This device is prevalent because the need to transport machines for various purposes has increased. After all, the number of infrastructure projects has also increased. There is a large number of already implemented solutions that have been used so far but are still used in some cases. Some of these solutions are described in papers [1-3]. Depending on the degree of automation, there are simpler and more primitive solutions, as shown in Fig. 1, where the loading ramp is being moved manually, using human power, or possibly using the working device of the machine being transported.

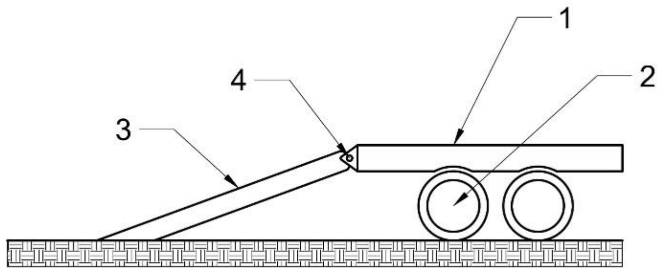

Fig. 1 *Illustration of the solution with manual manipulation of the loading ramp*

Fig. 1 shows components such as (1) the carrying platform, (2) pneumatics, (3) loading ramp, and (4) loading ramp support.

Over time, springs were added to the original first solution to help raise the loading ramp, as shown in Fig. 2. where can be seen components such as (1) the carrying platform, (2) pneumatics, (3) the loading ramp, and (4) swathe springs.

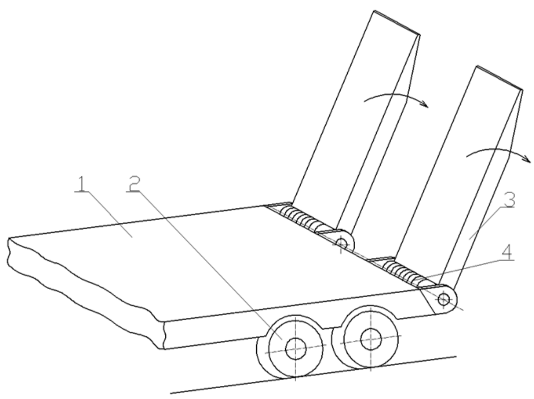

Fig. 2 *Solution with swathe springs [2]*

The solution, which eliminated the use of human power or additional devices, involved the installation of a hydraulic cylinder near the ramp support on the trailer.

Although this solution eliminated human participation in moving the ramp, it still has disadvantages regarding the load on the members of the mechanism and the force required to start the ramp.

By choosing more carefully the place of support of the hydraulic cylinder and its connection with the ramp, the manipulation of the ramp can be achieved with a smaller amount of energy consumed and less load on the members of the ramp mechanism. The mechanism scheme that enables this is shown in Fig. 3 and is described in more detail in the paper [3].

The components of the system shown in Fig. 3 are: (1) the carrying platform, (2) pneumatics, (3) loading ramp, (4) loading ramp support, (5) the vehicle being transported, (6) hydro-cylinder support, (7) a lever of a complex shape, (8) hydro-cylinder, (9) mechanism rod.

The advantage of using this solution is that the lever system reduces the force in the hydraulic cylinder used to start the ramp.

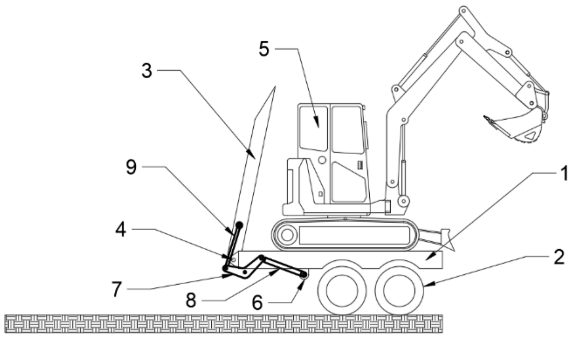

Fig. 3 *Illustration of the solution with a system of levers and a hydro-cylinder [3]*

The force reduction is made possible using a lever system that increases the force arm that balances the entire mechanism. The larger the arm of the force, the greater the normal distance of the axis of the mechanism member from the point of support, and the smaller the force required for balancing the mechanism will be. Influence on the reduction of force in the hydraulic cylinder can be achieved by choosing the appropriate lengths of the mechanism members, i.e. the length of the levers, defining the angle of the compound lever, and choosing the appropriate support positions, both the lever support and the hydraulic cylinder support. Appropriate dimensions and positions can be found through the optimisation process, which can be found in the paper [4].

Optimisation begins with creating a mathematical model to describe the corresponding phenomenon or mechanism mathematically. Of course, it is necessary to introduce certain limits for optimisation variables and constraints. Metaheuristic algorithms were used in this paper, and given that several different algorithms were used, a comparative analysis of the obtained results was given. Some algorithms give good results for a specific category of mathematical problems and models, but some algorithms are not suitable for solving them. Indeed, both algorithms give some results, but only certain ones give favourable results. That is, their objective function has a superior value compared to other algorithms. At the beginning of the research, before the optimisation process, we did not know which algorithms would be suitable for application to the given problem, so it is necessary to try several different algorithms and single out those that achieve the best results.

2 MATHEMATICAL MODEL

Mathematical models can significantly facilitate the implementation of scientific research and obtaining specific scientific results. First of all, this refers to the fact that using the model can avoid conducting experiments on authentic objects, which can be extremely expensive and demanding. In addition to the high cost of experiments, a big challenge is spending precious time organising experiments on authentic objects, which often cannot even be performed due to various limitations.

In this case, the mathematical model consists of a series of equations that simulate the movement of the mechanism members. The movement of the characteristic points of the mechanism and the change in the angles that the axes of individual members of the mechanism overlap with the horizontal axis are described in more detail in the paper [3]. The mathematical model used for the analysis is shown in Fig. 4.

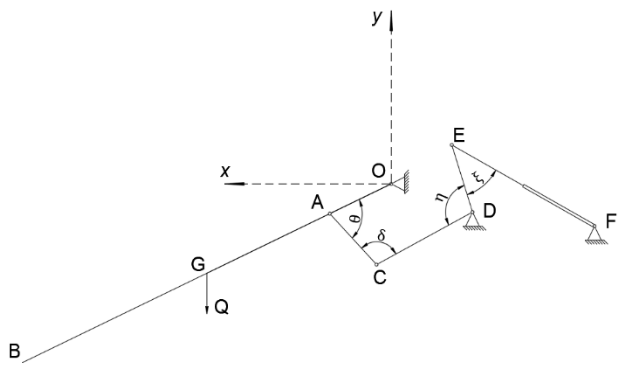

Fig. 4 *Mechanism wire model*

Based on Fig. 4, it can be concluded that the wire model of the mechanism was used for the mathematical model, which implies that the corresponding line elements correspond to the axes of the mechanism members. This way of displaying elements is possible because optimisation aims to obtain the most favourable lengths of the elements of the mechanism, not their cross-sections.

The shown wire model is located in the vertical plane, where the coordinate origin is defined at point O, representing the point of support of the loading ramp on the trailer.

The markings that can be seen in Fig. 4 are described in Table 1.

Table 1 Description of mechanism member labels

O	Coordinate system origin
A	The attachment point of the lever to the ramp
G	The centre point of the ramp
B	The endpoint of the ramp
C	The connection point between the levers of the mechanism
D	The point of support of the compound lever

	on the trailer chassis
E	The connection point between the lever of the mechanism and the hydraulic cylinder
F	The point of support of the hydraulic cylinder on the chassis of the trailer

The angles θ, δ, and ξ are the angles between the axes of the levers of the mechanism and can be seen in Fig 4.
Given that the vertices of these angles represent the pins that connect the mechanism's levers, the arms' mutual movement of these angles is not constrained so that the mentioned angles change their values during the movement of the mechanism. Points C, D, and E form a member of the mechanism called a compound lever. This component is obtained by joining the levers marked CD and DF, thus forming the angle between them which is marked with η. This constant angle represents one of the variables that are the subject of the optimisation process.
The lengths of the members of the mechanism used in the formation of the mathematical model are given in Table 2.

Table 2 Length labels for the optimisation process

OB	L_0	The length of the loading ramp
OA	L_1	The distance between the connection point of the lever and the ramp
AC	L_2	Mechanism lever length
CD	L_3	The length of the compound lever segment of the mechanism
DE	L_4	The length of the compound lever segment of the mechanism
FE	L_{FE}	The current length of the hydraulic cylinder
DF	L_{DF}	The distance between the supports of the compound lever and the hydraulic cylinder
OD	L_{OD}	The distance between the supports of the compound lever and the loading ramp

The mechanism for raising and lowering the loading ramp is loaded by the force originating from the self-weight of the members of the mechanism. In this case, only the mass of the loading ramp is known, so its effect was included in the consideration, while the effects of the masses of the members of the mechanism were neglected due to the lack of data on their cross-sections. The assumed mass of the loading ramp is 500 kg, and the weight force originating from this mass is marked with FQ, acts at point G and is directed vertically downward, as can be seen in Fig. 4. The initial and final positions of the loading ramp and members of the mechanism for its raising and lowering are shown in Fig. 5.
Based on these figures, it can be concluded that for creating a mathematical model, it was necessary to define auxiliary angles that enable the creation of a connection between the movements of certain mechanism members.

The procedure for determining the mechanism's appropriate lengths, angles and movement is described in detail in the paper [3], so only some main equations of the described model will be listed here.

The length that defines the stroke of the hydraulic cylinder, as one of its most essential characteristics, is calculated using Eq. (1).

$$L_{FE} = \sqrt{(X_E(i) - X_F)^2 + (Y_E(i) - Y_F)^2} \quad (1)$$

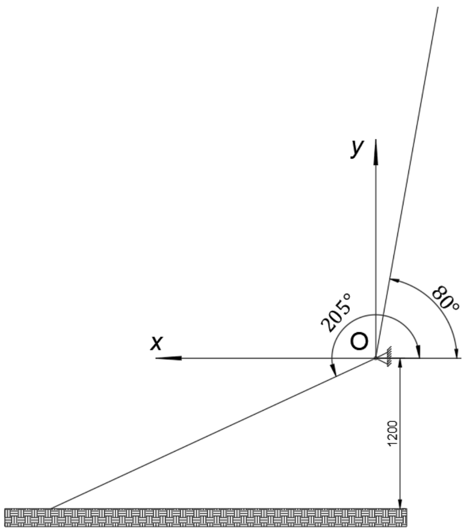

Fig. 5 *The position of the ramp at the beginning and end of the movement [3]*

Figures 6 and 7 allow the creation of equations describing the mechanism's movement in the vertical plane.

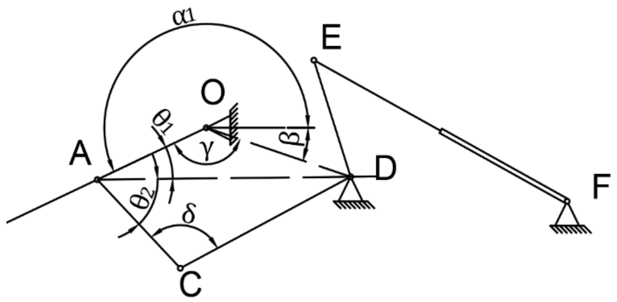

Fig. 6 *Auxiliary angles between members of the mechanism [3]*

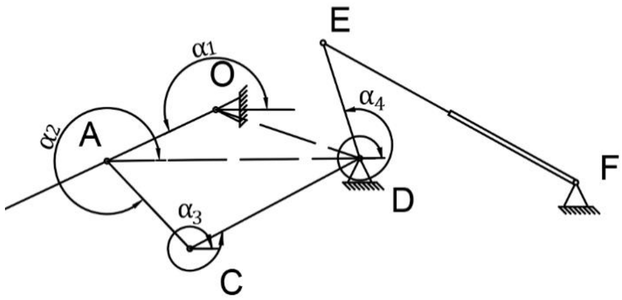

Fig. *7 Angles between the mechanism members and the horizontal axis [3]*

Given that the ramp occupies a range of angles with the horizontal axis, a counter was introduced that defines the angle change when moving the ramp. That counter is denoted by *i* so that when *i* has the value 1, the ramp's angle with the horizontal axis is α_1=80 degrees.

The stroke of the hydraulic cylinder, which is required to achieve the desired movement of the ramp from the initial to the final position, is calculated using Eq. (2).

$$stroke = L_{FE}(end) - L_{FE}(start) \tag{2}$$

The stroke of the hydraulic cylinder is obtained as the difference in the length of the hydraulic cylinder at the end and the beginning of the movement.
The characteristic of the hydraulic cylinder based on which its selection is made is the force that needs to be realised to enable movement. The equations used to calculate the force that needs to be realised in the hydraulic cylinder derive from the equilibrium conditions of the mechanism. This equilibrium condition implies two-moment equations from which specific forces are obtained. The moment equations are obtained based on Fig. 8 and Fig. 9. The impact of the position of the hydraulic cylinder mounting point can be seen in [4].

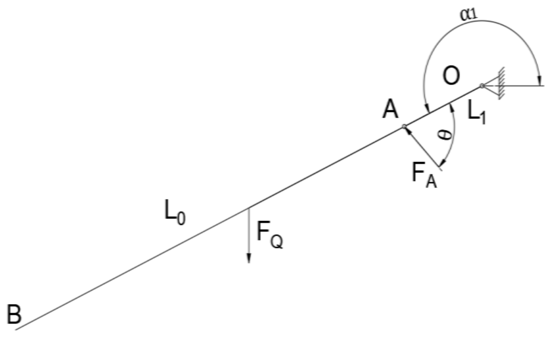

Fig. 8 *The wire model described by Eq. (3) [3]*

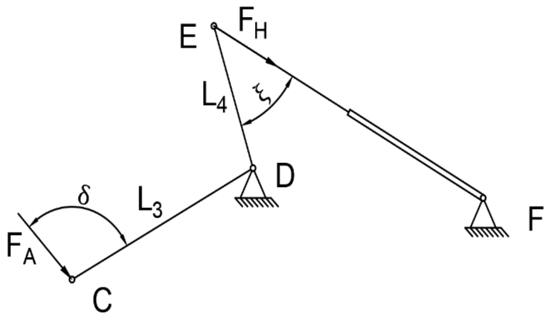

Fig. 9 *The wire model described by Eq. (4) [3]*

$$\sum M_O = Q \cdot \frac{L_0}{2} \cdot \cos(\alpha_1) - F_A \cdot L_1 \cdot \sin(\theta) \tag{3}$$

$$\sum M_D = F_A \cdot L_3 \cdot \sin(\delta) - F_H \cdot L_4 \cdot \sin(\xi) \tag{4}$$

To prevent the movement of the members of the mechanism, i.e. to achieve balance, it is necessary to equalise the equations (3) and (4) to zero. After that, the equations that enable the calculation of the force in the hydraulic cylinder are obtained and shown in Eq. (5) and Eq. (6).

$$F_A(i) = \frac{-F_Q \cdot L_0 \cdot \cos(\alpha_1(i))}{2 \cdot L_1 \cdot \sin(\theta(i))} \tag{5}$$

$$F_H(i) = \frac{-F_A(i) \cdot L_3 \cdot \sin(\delta(i))}{L_4 \cdot \sin(\xi(i))} \tag{6}$$

The final equation for calculating the force in the hydraulic cylinder is given by Eq. (6), and it can be concluded that depending on the position of the ramp, it changes its value.

3 DESCRIPTION OF THE OPTIMISATION ALGORITHMS

In recent years, there has been a proliferation of novel general-purpose metaheuristic algorithms. No free lunch theorem [5-6] justifies further development and research since, according to it, no single optimisation algorithm gives the best solution for all of the optimisation problems. Authors of the papers which present the algorithms, such as [7-9], usually provide some results for the most common benchmark examples so the newly presented algorithm can be compared to the existing ones. However, the functions used to compare the efficiency of the algorithms can be misleading when the algorithm has to be chosen for solving a specific engineering problem.
For this paper, the performance of four recent metaheuristic optimisation algorithms was compared on the same optimisation problem in the same conditions in the search for the optimal solution: Supply-Demand-Based Optimisation (SDO) [10], Marine predators algorithm (MPA) [11], Slime mould algorithm (SMA)[12], and Search and rescue optimisation algorithm (SAR) [13]. Like other metaheuristic algorithms, they all consist of exploration and exploitation phases interchanging through the optimisation processes. The exploration phases rely on picking random values from the given interval of optimised variables, while the exploration phases rely on the evolution of the solution through the iterations, also employing some randomness factor. The exploration phase aims to avoid the algorithm converging to a local optimum, while the exploitation phase represents the search around the local minima.

4 OBJECTIVE FUNCTIONS, LIMITS OF SEARCHING AREA, AND CONSTRAINTS

4.1. Objective function

The optimisation process involves defining the objective function by which the formed mathematical model is used to obtain a variable's minimum or maximum values. In this case, the force in the hydraulic cylinder required to move the mechanism is minimised. The equation for calculating the force in the hydraulic cylinder depending on the position of the ramp during its movement was obtained using a mathematical model. In general terms, the objective function is defined by Eq. (7).

$$o = F_H \tag{7}$$

Given that the mechanism moves in an extensive range of angles and moves from the first to the third quadrant of the coordinate system, attention must be paid to the sign of the force value. The movement of the hydraulic cylinder, i.e. its retracting or extraction, defines the direction of the force created by the hydraulic cylinder. Depending on the direction of movement of the hydraulic cylinder, the sign of the force value calculated by Eq. (6) changes.

An integral part of the objective function is the penalty function, which avoids those solutions that are not realistically feasible in obtaining the results of the optimisation variables.

4.2. Limits of searching

For the optimisation results to be used in real life, the limit values of the optimisation variables must be defined. In this paper, the optimisation of nine variables representing three different types of dimensions is carried out. Those optimisation variables are the length of the mechanism L1, L2, L3 and L4 levers, the angle η, and the coordinates of the compound lever and hydraulic cylinder supports. The order of optimisation variables is shown in Eq. (8).

$$OV = [L_1, L_2, L_3, L_4, \eta, X_D, Y_D, X_F, Y_F] \quad (8)$$

The numerical values of the lower and upper limits of the optimisation variables are given by Eq. (9) and Eq. (10).

$$LB = [300,300,300,300,50,200,-400,1000-400] \quad (9)$$

$$UB = [1500,1500,1500,1500,160,1000,0,1600,0] \quad (10)$$

4.3. Constraints

In addition to the limit values of the variables, defining the limitations also plays a significant role in shaping the solution at the end of the optimisation procedure. The constraints used in the optimisation process are described in detail in the paper [3] and are not presented in this paper. The constraints that are introduced into the mathematical model are used when defining the objective function, which was mentioned earlier. In this case, the limitations primarily refer to avoiding obtaining structurally impossible solutions. In this case, the constraints primarily refer to avoiding obtaining structurally impossible solutions, such as a solution involving encroaching one element into another element or vehicle chassis.

The constraints used in the optimisation procedure refer to the positions of the members of the mechanism at the beginning of the movement, i.e. in the initial position, during the movement of the ramp, as well as at the end of the movement of the ramp, i.e. in the final position.

One of the crucial constraints is the limitation of the stroke of the hydraulic cylinder, which, in addition to not having an enormous value, must not have a value greater than the initial length of the hydraulic cylinder, i.e. the length of the fully retracted hydraulic cylinder.

5 RESULTS AND DISCUSSION

The authors of the original papers provided the source code for used optimisation algorithms [10-13]. They were all adjusted and configured in the following way:

- T=1000 – the total number of completed iterations;
- N=60 – the number of searching agents;
- dim=9 – the problem's dimension corresponding to the number of optimised variables.

The number of searching agents for the SAR algorithm was changed to correspond to recommendations from the paper [13], where it was stated that the optimal number of searching agents equals double the number of optimised variables, so in this case, it equals 18.

All four algorithms were run 100 times each, and the values of the objective functions obtained through the optimisations are presented in the form of the box diagrams in Fig. 10.

It can be seen that the best values were obtained using SAR and SDO optimisation algorithms, where the objective function values within 100 optimisation runs are the lowest and the most consistent, meaning that these two algorithms have a higher chance of reaching the best solution. SMA also reaches consistent values of the objective function through 100 runs. However, these values are considerably worse compared to the other three algorithms.

In Fig. 11, oscillations of the obtained values of the objective function per run of SAR, SDO and MPA algorithms were given. These diagrams show how the value of the objective function can differ from run to run of the optimisation.

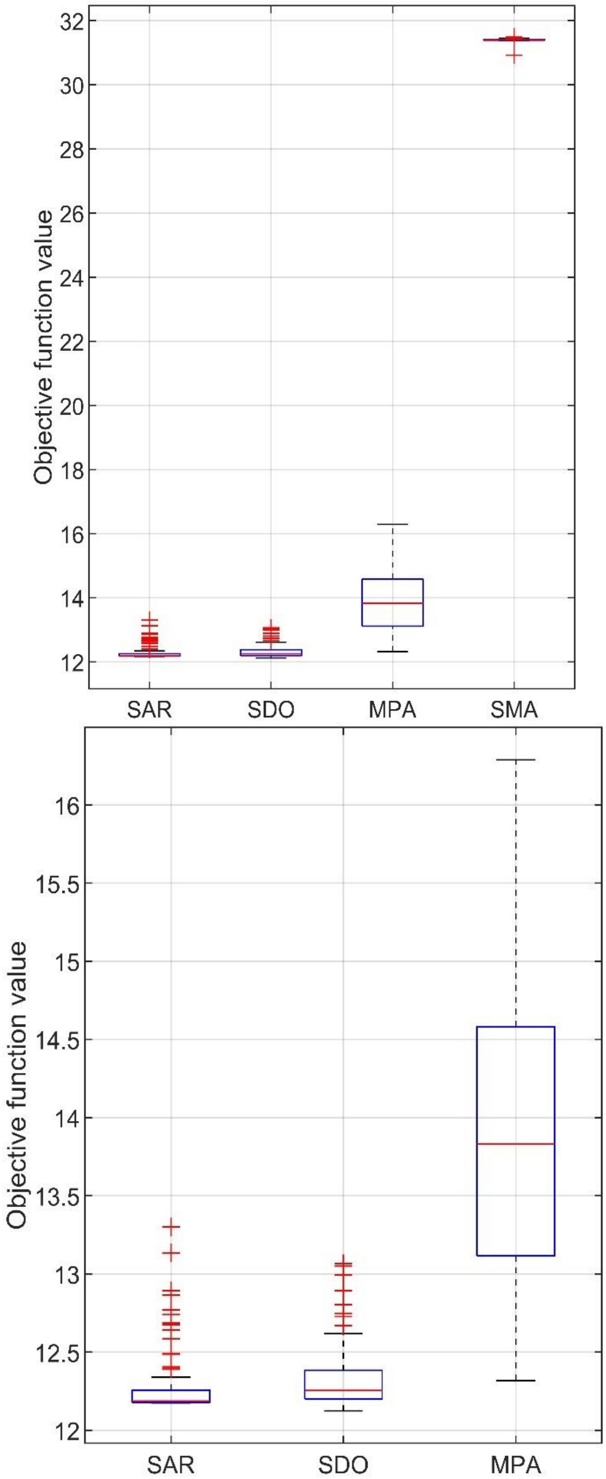

Fig. 10 *Box diagrams for SAR, SDO, MPA and SMA algorithms run 100 times*

Table 3 The optimisation results after 100 runs per optimisation algorithm

Algorithm	F(x)	STD	%
MPA	12.31850344	0.907375139	1.577088179
SAR	12.17457752	0.207939632	0.41354814
SDO	12.12422978	0.196752116	0
SMA	30.9252364	0.053679695	60.79502958

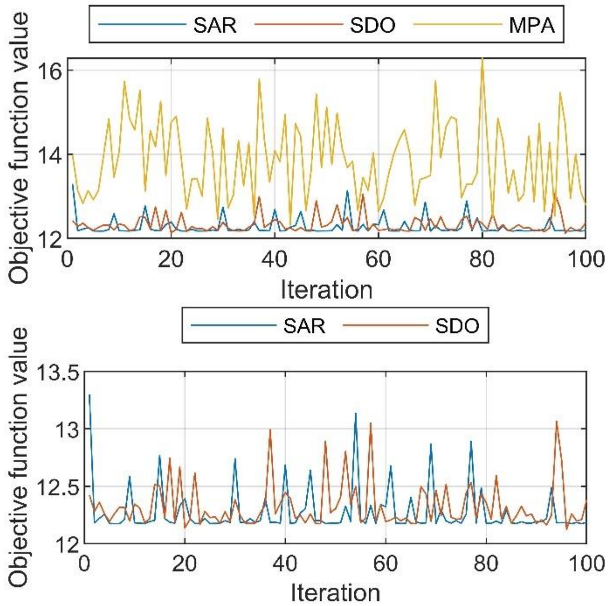

***Fig. 11** Oscilaction of the best obtained value through the optimisation runs*

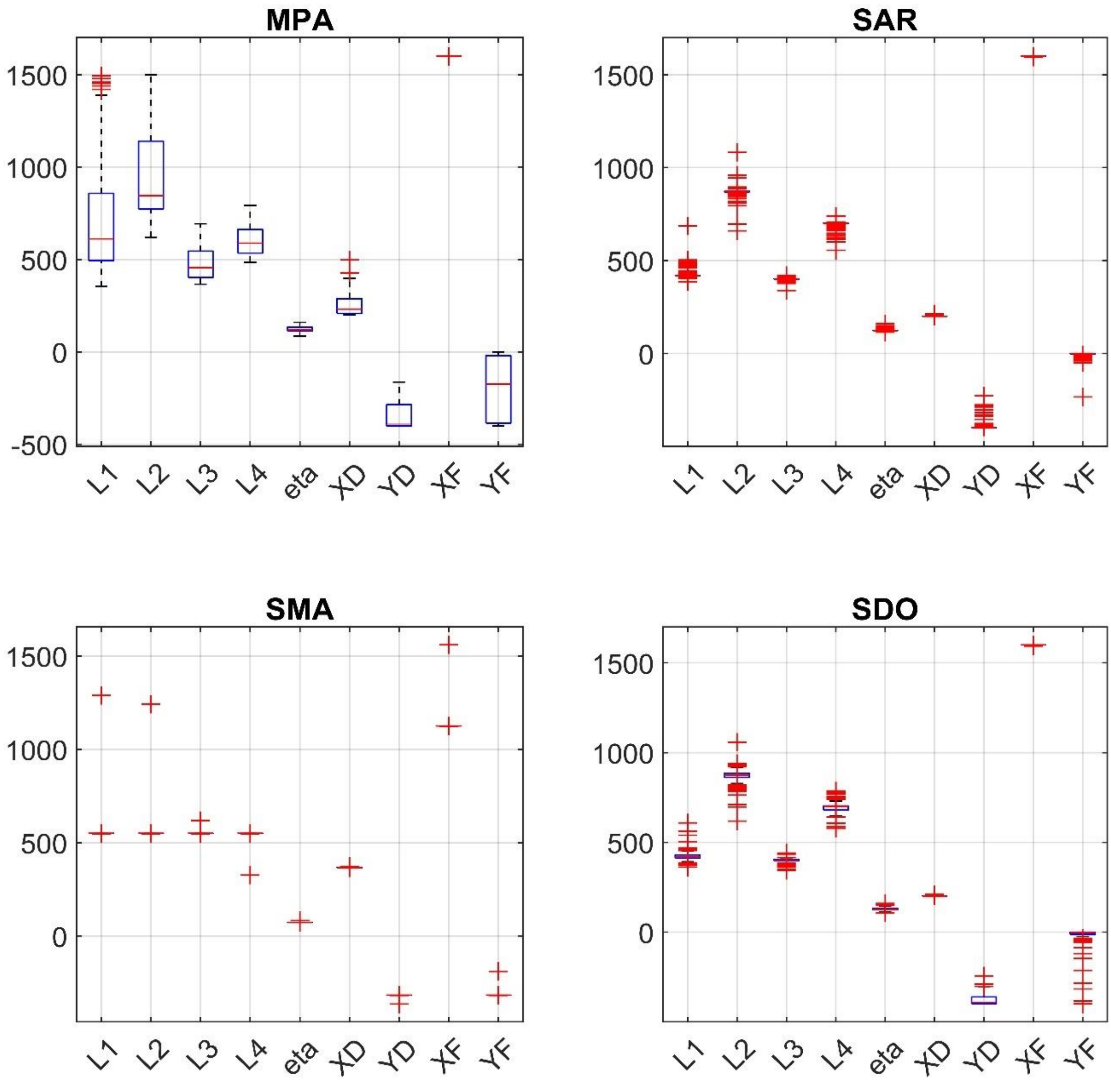

***Fig. 12** Searched space of the variable values for the 100 best solutions for each algorithm*

Table 4 The best optimised variable values after 100 runs per algorithm, for each of the algorithms

	L1	L2	L3	L4	eta	XD	YD	XF	YF
MPA	372.76533	839.58542	391.430613	764.028252	136.30288	200.000216	-399.564284	1599.999	-391.84988
SAR	418.78334	872.43987	400.303771	700.513773	123.417377	200.00140	-399.999994	1599.999	-0.0035154
SDO	377.01294	887.03806	408.864139	777.970230	142.438766	200.14530	-390.989588	1599.892	-399.58099
SMA	1288.2427	1241.3005	618.07500	326.593734	82.561578	372.699438	-363.739392	1559.449	-188.98117

Table 3 shows the best-obtained values of the objective function after 100 runs per algorithm and the standard deviation of the best value through the 100 runs. It can be seen that the best value of the objective function equals 12,12422978, and it was obtained using the SDO optimisation algorithm.

The next best value was obtained using the SAR optimisation algorithm, and the difference between the value obtained with SDO and SAR equals 0,41%. The SDO has a lower standard deviation compared to SAR as well. The SMA optimisation algorithm presents the lowest standard deviation; however, this algorithm obtains the worst objective function value, which is 60,7% higher compared to the one obtained using the SDO optimisation algorithm.

This is also represented in Fig. 10, where the box diagram for the SMA algorithm takes the smallest amount of space compared to the others. However, it is positioned higher on the scale. The worst standard deviation through 100 algorithm runs is present with the MPA optimisation algorithm, which gives its best solution, which is 1,58% higher than the SDO.

In Fig. 12, the values of optimised variables for the best solution for each of the 100 runs per algorithm were visualised. It can be seen that the higher standard deviation through the optimisation runs means a more significant number of different solutions in different areas of the search space. For example, it can be noted that the SMA algorithm mostly picks the same values of the optimised variables as the best solutions as the objective function converges to the best solution. On the other hand, the SDO algorithm gives a more extensive variety of optimal solutions through different optimisation runs. This behaviour implies that if the algorithm is run only a few times, the best solution the SDO algorithm can reach might not be reached. However, every solution the SDO algorithm gives as the best solution per run is better than the best solution obtained using SMA.

Despite the excellent performance of the MPA optimisation algorithm seen in the literature [14-15], this algorithm did not prove efficient, especially considering Fig. 11, where it can be seen that most of the obtained values in 100 runs are higher compared to those obtained in any run of the SDO and SAR optimisation algorithms.

The optimal value obtained by each of the algorithms, considering all 100 runs, is displayed in Table 4. The solution obtained with the SDO algorithm, with the objective function value equal to 12,12422978 kN, is illustrated in Fig. 13.

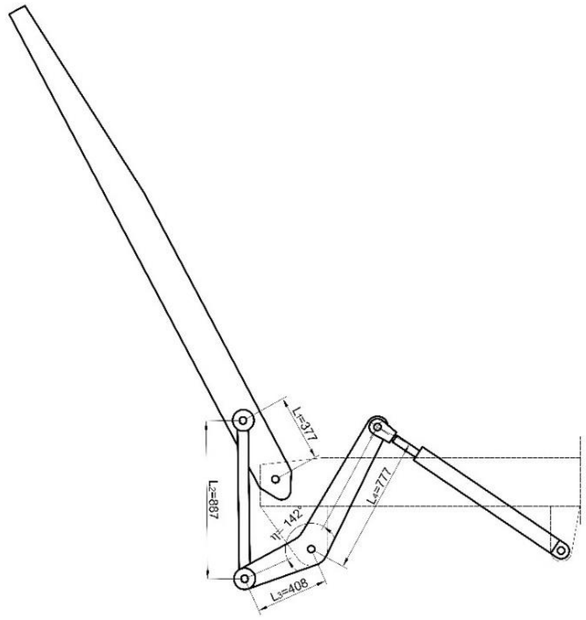

Fig. 13 *Illustration of the optimal solution*

The hydraulic-cylinder force change diagram for the optimal solution highlighted in Table 4 is given in Fig. 14.

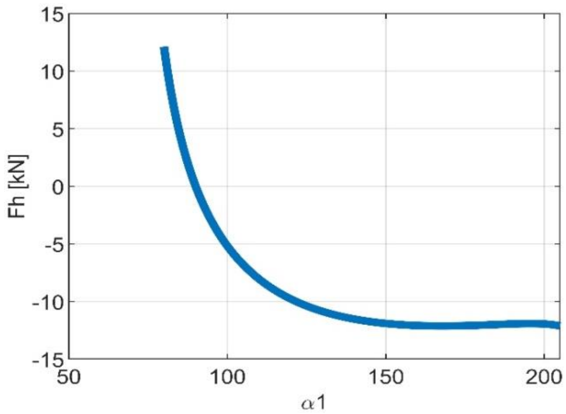

Fig. 14 *Hydraulic-cylinder force change*

6 CONCLUSION

The choice of the optimisation algorithm for the specific engineering problem, such as the heavy-weight loading ramp mechanism optimisation, can significantly impact the optimisation result. Even though some optimisation algorithms perform better on other optimisation problems and benchmark examples, this behaviour does not always convey to every engineering problem, confirming the conclusions from the [5-6]. The most commonly used functions for benchmarking the optimisation algorithms can be misleading, especially knowing that some of the optimisation algorithms contain certain biases towards them, which is investigated in [16] which implies that more research is needed to find benchmark functions that could be used for testing these algorithms on realistic engineering problems.

The results show that the difference between the best values obtained with different optimisation values can be as high as 60%. The random nature of the metaheuristic algorithms means that a different solution can be reached with each run. The new solution can be better or worse. Different algorithms have lower differences between the reached solutions through runs. For this problem of finding the optimal design parameters for the heavy-weight loading ramp mechanism, the SDO and SAR optimisation algorithms proved to be adequate, giving the optimal solution with slight variations between the optimisation runs.

With this in mind, it was proven that the metaheuristic optimisation algorithms can be successfully utilised in the mechanism synthesis process and can significantly improve the performance of a mechanism such as the one for a heavy-weight loading ramp.

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ANALYSIS OF DEPTH AND ANGLE OF DIGGING RESISTANCE ON THE STABILITY OF CRAWLER TRACTOR

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Abstract

In this paper, a mathematical model and program for influence analysis depth and angle of ripping resistance on the stability of crawler tractor with ripper manipulator are developed.

Key words: *crawler tractor*, *ripper manipulator*

1 INTRODUCTION

Crawler tractors are heavy construction machines commonly used in construction, mining, and agriculture for earthmoving tasks. These machines perform a wide range of functions due to their combination of features.
Since they can fulfill multiple functions, these machines are crucial for mining and construction work, as they increase production and efficiency. Their mobility makes them valuable tools for earthmoving projects. Crawler tractors have a tracked undercarriage that provides stability and traction on uneven, soft, or challenging terrain.

The tracked undercarriage distributes the machine's weight over a larger surface area, reducing the pressure on the ground and preventing sinking into soft soil. The loader aspect of crawler tractors is characterized by a large blade mounted at the front, depending on the specific model and application. This tool can be used for lifting and transporting materials such as soil, gravel, sand, and others. The bucket can be positioned at an angle for leveling or pushing materials. Crawler loaders can also be equipped with a ripper attachment with teeth at the rear of the machine. The ripper is designed to break compacted soil, rocks, or hard surfaces and is typically used in construction and mining to prepare the ground for excavation or other activities. So, tractors achieve their primary functions through manipulators with tools in the form of a blade and a ripper with tearing teeth. The manipulators are used simultaneously or, if necessary, alternately.In order to ensure safe and efficient operation of the crawler tractor with a ripper manipulator, an analysis of ripping resistance was conducted, considering both static and hydraulic stability conditions. As an example, the analysis covered a crawler tractor from the company Brana Komerc from Kruševac.

2 PHYSICAL MODEL

The kinematic chain of the ripper manipulator consists of four main members: the connecting plate L_2 (Fig. 1a), the lower lever L_3, two identical upper levers L4, and the carrier with three tearing teeth L_5. The connecting plate L_2 is an adapter plate, a welded construction that has four identical lugs on one side for connection to the lugs on the crawler tractor, and on the other side, lugs for attaching the lower and upper levers and the ripper hydraulic cylinder. Members of the ripper's kinematic chain are welded constructions, except for the upper levers, which are shaped by cutting from steel plates. The ripper teeth are connected to the carrier with a vertical joint that allows the teeth to rotate freely depending on the lateral ripping resistance. The members of the kinematic chain are connected by rotary joints with sliding steel sleeves, forming a mechanism in the shape of a parallelogram. The driving member of the ripper mechanism is a bidirectional hydraulic cylinder L_c connected, with spherical joints, at one end to the lugs on the connecting plate and at the other end to the pin of the joint connecting the upper levers and the tooth carrier.

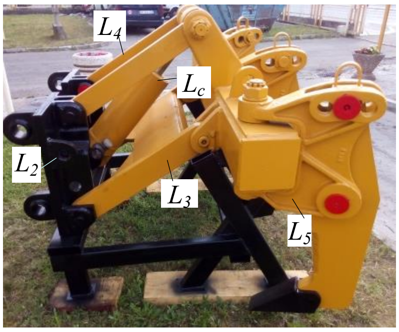

Fig. 1 Ripper of Brana Komerc company

The required parameters of the members of the kinematic chain and the drive mechanism, hydraulic cylinder, and ripper were determined according to the design documentation and based on the analysis of the physical model of the crawler tractor with a ripper from Brana Komerc Kruševac.

2.1. Mathematical model

Based on the physical model of the tractor with a ripper, a mathematical model has been developed for the analysis of the kinematics and loads of the ripper. In the mathematical model, the tractor L_1 (Fig. 2) together with the kinematic chain of the ripper is observed in the absolute coordinate system *OXY*, where the *OX* axis lies in the horizontal plane of the machine's tracked undercarriage, and the vertical axis

OY passes through the axis of the ears to which the lower and upper levers and the ripper hydraulic cylinder are attached. The connecting-adaptive plate L_2 is, on one side, attached to the tractor L_1 with hinges O_{21} and O_{22}, and on the other side to the plate, with rotating joints O_3 and O_4, connecting the lower L_3 and upper L_4 levers of the ripper, at whose ends, in rotating joints O_5 and O_7, the tooth holder L_5 is attached [1].

The tractor and the kinematic chain members of the ripper in the mathematical model are defined in their local $O_ix_iy_i$ coordinate system by a set of quantities [2]:

$$L_i = \{\hat{\boldsymbol{e}}_i, \hat{\boldsymbol{s}}_i, \hat{\boldsymbol{t}}_i, m_i\} \tag{1}$$

where: $\hat{e}_i$ - the unit vector of joint O_i axis which connects member L_i to the previous member $L_{i-1,}$ $\hat{s}_i$ - the vector of the position of joint O_{i+1} center which is used to connect the chain member L_i to the next member L_{i+1}, $\hat{t}_i$ - the vector of the position of the member mass center, m_i - the member mass.

The driving member of the ripper mechanism is a two-way hydraulic cylinder witch are defined with set of size:

$$C_i = \{d_{11}, d_{12,}, l_p, l_k, m_{ci}, n_{ci}, p, p_o, Q\} \tag{2}$$

where: d_{i1}, d_{i2} - the diameter of the piston and the piston rod hydrocylinder driving mechanisms of ripper, $l_{p,}$ l_k - initial and ended length of the hydraulic cylinder m_{ci}, n_{ci} - mass and the number of hydraulic cylinder, p, p_o – maximum and return pressure of the ripper hydraulic cylinder, Q – flow rate of the ripper hydraulic cylinder. The internal (generalized) coordinates of the mathematical model of the ripper kinematic chain represent the angles θ_i (sl.2) of the relative position of member L_i in relation to the previous member L_{i-1} during rotation around the joint axis O.

By changing the length c of the hydrocylinders of the ripper drive mechanism in the interval of limit values $c=[c_p, c_k]$ the generalized coordinates θ_i in the interval $\theta_i=[\theta_{ip}, \theta_{ik}]$ also change, where: θ_{ip} - he initial and θ_{ik} - the final angle of the relative position of member L_i in compared to the previous member L_{i-1} .

The transitional matrices are used to convert quantities of member L_i from the local coordinate system $O_i\, x_i\, y_i\, z_i$ to the absolute coordinate system *OXYZ*.

During the ripper load analysis, the ripper operating conditions were simulated determined by the adhesion coefficient of the tracks on the tractor's moving base and the impact load coefficient of the ripper.

Za simulirane uslove rada, analizom su određene moguće sile otpora razrivanja W na vrhu zuba ripera iz uslova statičke W_s i hidrauličke W_c stabilnosti traktora sa manipulatorom ripera: For the simulated working conditions, the analysis determined the possible ripping resistance forces W on the top of the ripper teeth from the conditions of static W_s and hydraulic W_c stability of the tractor with the ripper manipulator:

$$W = \{W_s, W_p, W_c\} \tag{3}$$

According to the condition of stable operation of the tractor (non-lifting and non-sliding), the limit force of ripping resistance W_s is determined according to the direction of the force of ripping resistant, depending on the angle α_w of the action of the resistance force from the equilibrium conditions $\Sigma M_{o11}=0$ and $\Sigma M_{o12}=0$ set for the potential overturning line O_{11} or O_{12} tractors:

- in case $\alpha_w \le 0^o$:

$\Sigma M_{o11}=0$; the condition of non-lifting the tractor

$$W_s \cdot r_{w11} + g\sum_{i=1}^{5} m_i x_{ti} = 0 \tag{4}$$

- in case $\alpha_w \ge 0^o$:

$\Sigma M_{o12}=0$; the condition of non-lifting the tractor

$$W_s \cdot r_{w12} - g\sum_{i=1}^{6} m_i (l + x_{ti}) = 0 \tag{5}$$

- in case $\alpha_w = 0^o$; the condition of non-sliding the tractor:

$$W_p = \frac{1}{\cos\alpha_w}\eta_p g\sum_{i=1}^{6} m_i \tag{6}$$

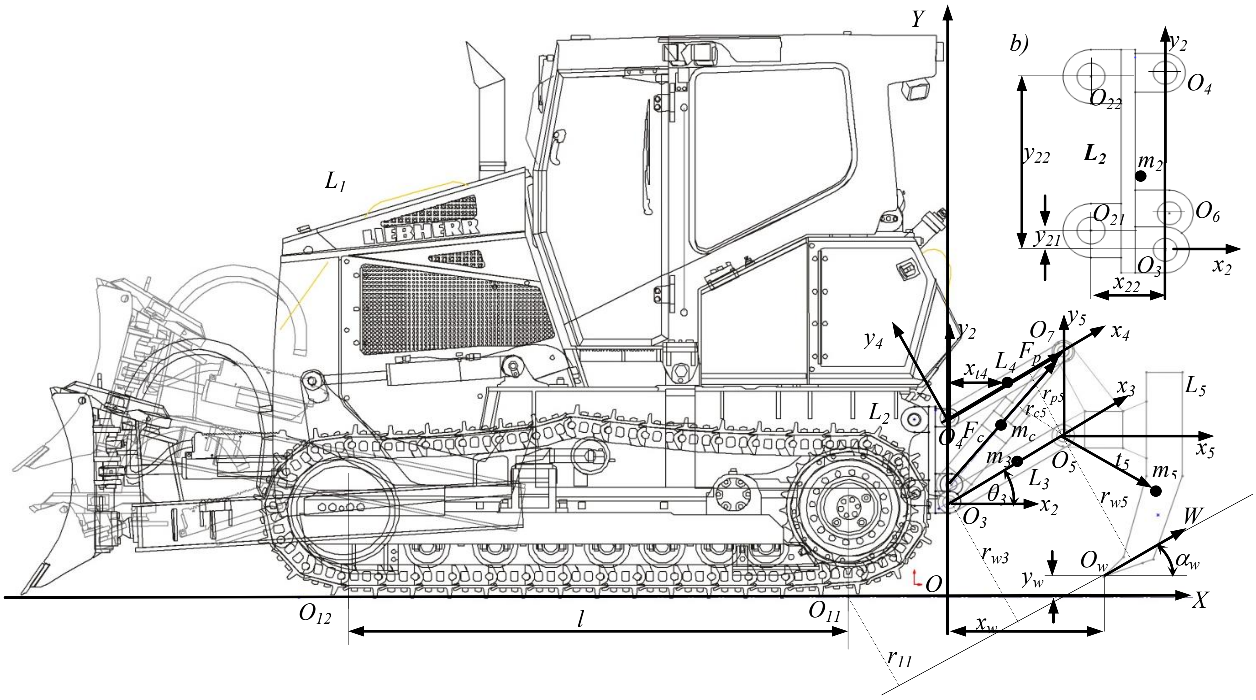

Fig. 2 Mathematical мodel of crawler tractor and a pipper Brana komerc

where: l - the length of the tracks, r_{w11},r_{w12}- - the arm of the action of the digging resistance force for the relative lines of the tractor roll depending on the angle α_w of the action of the digging resistance force, x_{ti} – the x coordinate of the position of the center of mass of the members of the kinematic chain of the tractor with ripper.

According to the condition of hydraulic stability of the drive system of the ripper manipulator, the limit force W_c of the digging resistancethat can be overcome by the maximum force F_c of the hydraulic cylinder of the ripper is determined from the equilibrium condition $\Sigma M_{O3}=0$ for the joint O_3 of the ripper expressed by the equation [4]:

$$W_c \cdot r_{w3} - F_c \cdot r_{c3} - F_p \cdot r_{p3} - M_{g3} = 0 \qquad (7)$$

and equilibrium conditions $\Sigma M_{O5}=0$ for joint O_5 of the ripper expressed by the equation:

$$W_c \cdot r_{w5} - F_c \cdot r_{c5} - F_p \cdot r_{p5} - M_{g5} = 0 \qquad (8)$$

where: r_{w3}, r_{w5} -arm of action of the digging resistance force for the axes of joints O_3 and O_5 of the ripper, r_{c3}, r_{c5} - arm of action of the maximum force of the hydraulic cylinder of the ripper for the axes of the joints O_3 and O_5, F_p - - force in levers L_4, r_{p3},r_{p5}- arm of action forces in levers for joint axes O3 and O5. By changing the force F_p in the levers from equation (7) to equation (8), the digging resistanceforce is obtained:

$$W_c = \frac{M_{g3} - M_{g5}\dfrac{r_{p3}}{r_{p5}} - F_c\left(r_{c5} - \dfrac{r_{p3}}{r_{p5}} r_{c5}\right)}{r_{w3} - \dfrac{r_{p3}}{r_{p5}} r_{w5}} \qquad (9)$$

The force in the hydraulic cylinder of the ripper is determined on the basis of defined sizes (2), and according to the technical documentation of the crawler tractor of the company Brana komerc Kruševac, by the equation:

$$F_c = \begin{cases} (p \cdot A_1 - p_o \cdot A_2) \cdot \eta_{cm} \text{ - when pulling out} \\ p \cdot A_2 - p_o \cdot A_1) \cdot \eta_{cm} \text{ - when retracting} \end{cases} \qquad (10)$$

where: p, p_o – maximum pressure in the discharge line and pressure in the return line of the hydraulic cylinder, A_1, A_2 – area of the piston and area of the piston on the side of the connecting rod, η_{cm}- volumetric degree of usefulness of the hydraulic cylinder.

During the spatial simulation of the ripper, the desired change in the position of the ripping teeth of the ripper manipulator is achieved by cyclically changing the length of the hydraulic cylinder of the ripper drive mechanism. The lengths of the hydraulic cylinders are changed from the initial c_p to the final c_k for the desired number N_c of the same increments - hydraulic cylinder stroke steps determined by the equation [4]:

$$\Delta c = \frac{c_k - c_p}{N_c - 1} \qquad (11)$$

For each position of the ripping teeth of the ripper manipulator, the angle of the direction of action of the ripping resistance is cyclically changed for the desired number of changes N_w within the limits from the set initial to the final value for the increment of the angle determined by the equation:

$$\Delta\alpha_w = \frac{\alpha_{wk} - \alpha_{wp}}{N_w - 1} \qquad (12)$$

By using the developed program based on the defined mathematical models of the ripper, the ripper tearing resistances in the entire working area of the tearing teeth from y_{wmin} to y_{wmax} were determined.

3. ANALYSIS OF RESULTS

The results of the analysis show (fig. 3a) that the maximum digging depth of the crawler tractor with the ripper manipulator is y_{wmin}=-413,33 mm mm at the length of the hydraulic cylinder c_p=700 mm, i.e. when the hydraulic cylinder is maximally retracted. At the end length of the hydraulic cylinder c_k=1045 mm (Fig. 3b), the maximum height of ripping is y_{wmax}=399,5 mm [3].

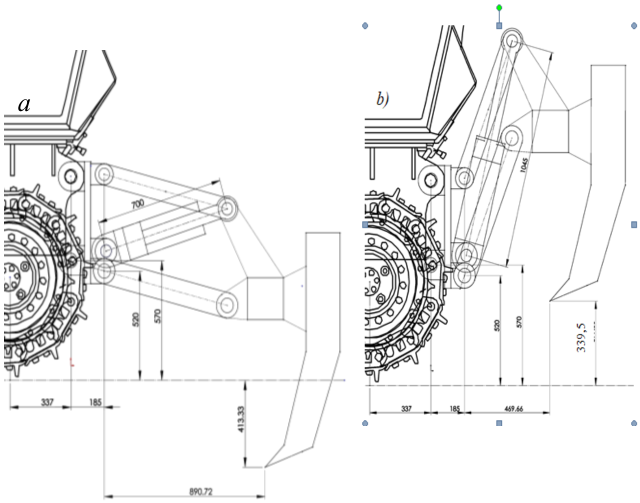

Fig. 3 Limit positions of ripper teeth of Brana komerc

During the ripper load analysis, normal and extreme conditions of the ripper were simulated, determined by the adhesion coefficient of the tracks on the tractor's moving base and the impact load coefficient of the ripper (table T1). The resultant W of possible digging resistance forces depending on the angle α_w of the digging resistance action direction and the ripper depth yw are shown in Figure 4. For the simulated operating conditions (table T1), the analysis determined the possible digging resistanceforces at the tip of the ripper teeth. The possible digging resistanceforce is determined as the minimum value of: a) the digging resistancelimiting forces determined from the conditions of stable operation of the tractor (non-lifting and non-slipping) and b) the digging resistancelimiting forces that can be overcome by the maximum ripper hydraulic cylinder force.

From the diagram (Fig. 4), can see, mainly, sudden changes in ripper digging resistanceas a consequence of the dependence given by equation (3). digging resistanceforces determined from the condition of the tractor not lifting and not sliding, and the digging resistancelimiting forces that can be overcome by the

Table 1 Simulation conditions

Working conditions	Normal	Extreme
The Adhesion coefficient of the tracks on the tractor's moving μ_p	*0,9*	*1,0*
The impact load coefficient of the ripper k_u	*1,0*	*1,2*
Number of hydraulic cylinder step changes N_c		*9*
Land category [2]		*II*
Initial and final length of the cylinder		$c_p/c_k=0,7/1,045m$
The number of changes in the direction of action of the digging resistance N_w		*5*
The range of the change of the angle of the direction of action of the digging resistance		$\alpha_w=80^{\circ}-(-80^{\circ})$

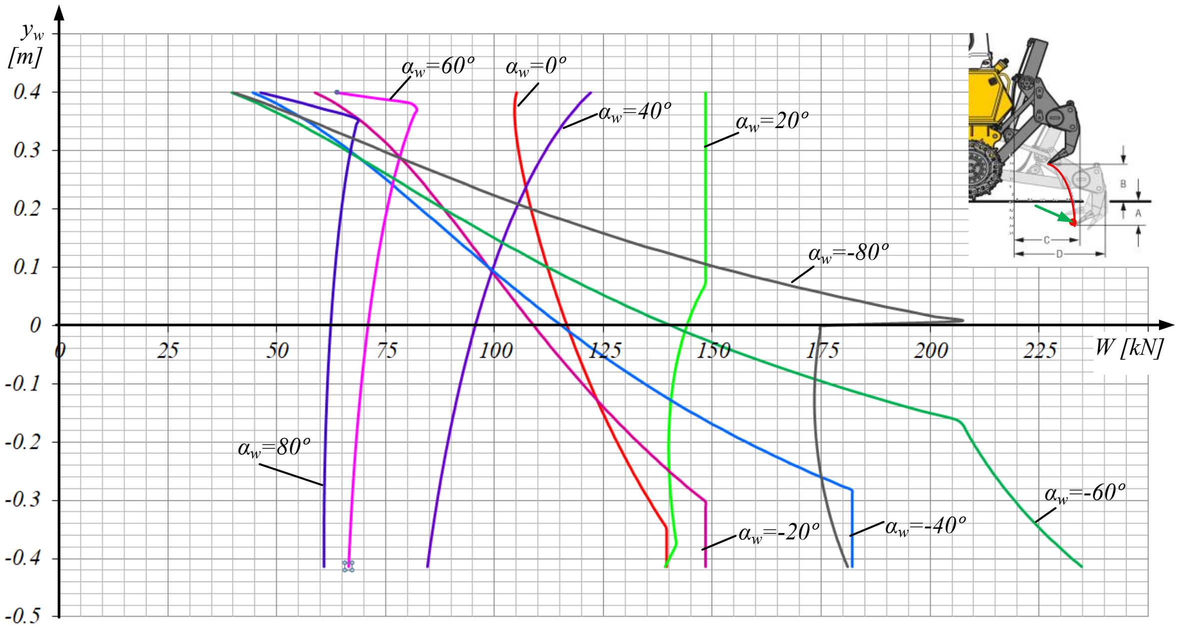

Fig. 4 Change of digging resistance

maximum force of the hydraulic cylinder of the ripper. In this sense, the characteristic change is the digging resistanceat the angle of the direction of action of the resistance $\alpha_w=-80^o$, when at the depth $y_w=0.007m$ the digging resistanceis $W=206,824$ *kN* and already at $y_w=-0,010m$ the digging resistanceis $W=174,986$ *kN*.

4. CONCLUSION

Crawler tractors are characterized by the ability to perform different functions of interrupting transport with different tools (different types of blades and different arms of the ripper manipulator). It is characteristic that when performing any possible functions in their radmon area, crawler tractors have different positions and working conditions. By using the developed mathematical model and program, the analysis of the forces of resistance to tearing of the crawler tractor in the entire working space of the ripper manipulator was performed. The presented research results show the working range - i.e., positions of the kinematic chain of the ripper manipulator and the working conditions under which the boundary resistance for ripping occur, based on the stable operating conditions of the tractor boundary resistance that the maximum force of the ripper hydraulic cylinder can overcome. According to the boundary resistance of a crawler tractor with a ripper manipulator, as well as a blade, a synthesis of the drive mechanism of motion transmission is carried out, which will be the focus of further research.

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DESIGN LAYOUT OF PLANETARY GEARBOXES CONTROLLED BY BRAKES ON SINGLE SHAFTS

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Abstract: Configurations of complex planetary gear trains consisting of two planetary gear trains of basic type are subject of this paper. Since these gear trains are formed by linking shafts from different planetary units and contain two carriers, they are designated as two-carrier planetary gear trains with four external shafts, from which two are single shafts and two are coupled shafts. Structural configurations are laid out, with additional research made into gear trains using coupled external shafts for torque input and output, with the controlling brakes acting on single external shafts. The kinematic schemes of all analyzed PGT variants have been created, and the available transmission ratio ranges have been calculated for both speeds. The transmission ratio is changed by alternating the activation of each brake, enabling their use with two transmission ratios.

Keywords:*two-speed planetary gear trains, design layout, external shafts, transmission ratio; brakes on single shaft*

1 INTRODUCTION

There are many benefits that are inherent to planetary gear trains (PGTs) which make them more suitable than classical gear trains. The most important of these advantages is a considerable reduction of mass and dimensions for the same torque rating. Because of that, the application of PGTs has been significantly expanded in various engineering applications.

PGTs as a totality, and particularly complex multi-carrier PGTs cover a vast area of technical knowledge [1]. By connecting the shafts of various gear train units, compound multi-carrier PGTs can be built. PGTs with two coupled shafts and four external shafts are a particular kind of complex multi-carrier PGTs which enable two-speeds. These PGTs have many advantages. The most frequently mentioned is the potential for transmission ratio changing under load. This presents a significant advantage in their application and might even be required in some cases.

There has been no systematic research into these PGTs until now. The review of 15 reversible transmission configurations with two coupled and four external shafts has been presented in [2], and rough transmission ratio values as well as rough efficiency values have been provided.

The procedure for selection of optimal PGT compound structures has been included in the software *DVOBRZ* and is based on suggestive systematic research delivered between 2006 and 2011 [3].

The selection of an optimal transmission of this type which can satisfy specific requirements is complex, and it can be performed by means of multi-criteria optimization. The usage of multi-criteria optimization to gear trains, and particularly planetary gear trains, has not been the topic of many studies, however an overview can be given.

In this paper structure and layout variants are depicted, first of all. Then, by placing the brakes on two shafts, a braking system is obtained in which the alternating activation of the brakes shifts the direction of the power flow through the planetary gear train and the transmission ratio.

The subject of the paper is layout variants of PGTs with brakes on single shafts. Design layout and kinetic features of PGTs of these transmissions are shown.

2 TWO SPEED COMPOUND PLANETARY TRAINS

A mechanism obtained by joining two shafts of one PGT unit to two shafts of the other PGT unit is shown in Fig. 1.

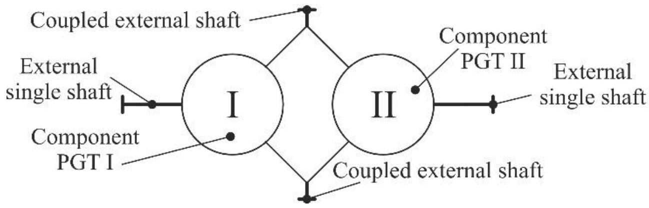


Fig. 1 *Compound train*

There are four external shafts, among which two are coupled and two are single external shafts. The whole mechanism is specified as the compound train, while planetary units are specified as component trains.

Both component trains are planetary gear trains of basic type, i.e., planetary gear trains comprising of a sun gear 1, planet gear 2, ring gear 3 and planet carrier *h*, as shown in Fig. 2. The ideal torque ratio and element torque ratios, besides the Wolf-Arnaudov symbol for this basic type of PGT are laid out in Fig. 2. As the negative transmission ratio is carried out by blocking the carrier, the carrier shaft is the summary element.

The ideal torque ratio is given by Eq. 1, while the torque ratios are defined by Eq. 2:

$$t = \frac{T_3}{T_1} = \left|\frac{z_3}{z_1}\right| = -i_0 > +1 \quad (1)$$

$$T_1 : T_3 : T_h = +1 : (-i_0) : (i_0 - 1) \quad (2)$$

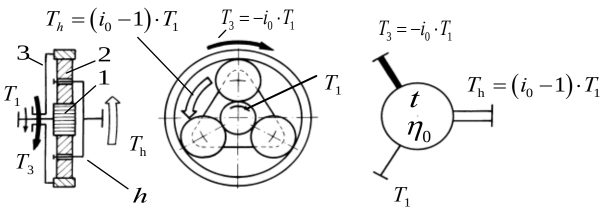


Fig. 2 *The most commonly used basic type of planetary gear train and its torques [1]*

Eqs. (1) and (2) are governed by the prerequisite of assuming ideal efficiency with zero losses (3):

$$\eta_0 = \eta_{13(h)} = \eta_{31(h)} = 1 \quad (3)$$

3 STRUCTURE AND LABELLING

The structure of compound planetary gear trains is depicted systematically in [4,5,6,7], however a brief description will be carried out in this paper. There are 12 distinct methods for component train connection in total [8]. An alphanumerical label (S11…S56) is joined to each of those 12 structural schemes, providing an indication of the component train shafts connection modes (Fig. 3). The brakes can be placed on external shafts, as well as input and output shaft, defining layout variants (label V1…V12), as shown in (Fig. 4).

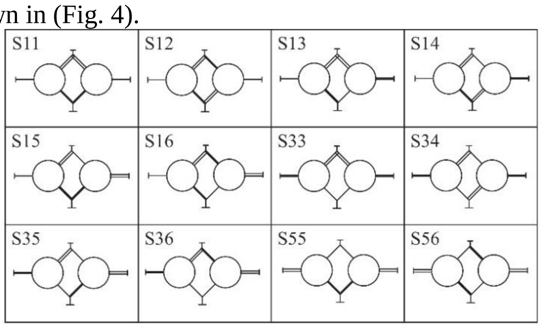
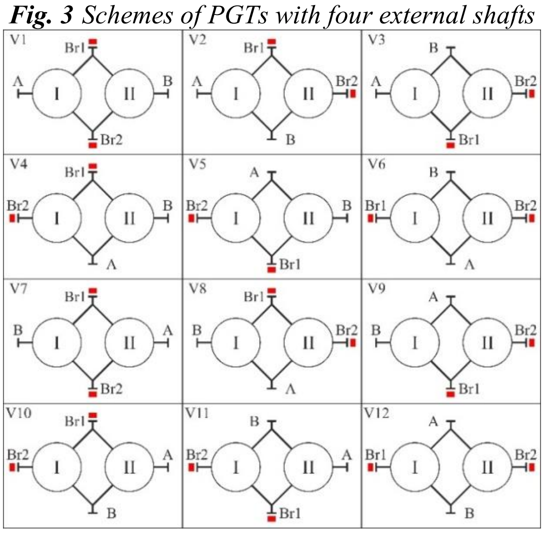


Fig. 3 *Schemes of PGTs with four external shafts*



A – input shaft; B – output shaft; Br1, Br2 – brakes; V1-V12 – layout variants

Fig. 4 *Layout variants systematization*

4 THE COMPOUND TRAINS PROCESS EXAMINATION

By placing the brakes on two shafts, a braking system is obtained in which the alternating activation of the brakes shifts the direction of the power flow through the planetary gear train, ultimately resulting in a variation of the transmission ratio.

Some compound planetary gear trains are depicted in [9, 3, 10, 4,11], while the possible power flows are analyzed, and transmission ratio at both component trains are derived in [12]. The achievable range of transmission ratios and efficiencies of both component gear units is laid out in [2], with 15 kinematic schemes being presented. A computer program for the choice of an optimal form of multi-speed PGTs is derived in [10], while the chart of changing capabilities for the realizable two-speed planetary gear trains was presented in [3].

There are three distinct groups of compound two-speed planetary gear trains referring to the brake layout. The first group relates to groups with brakes situated on coupled shafts, the second group includes gear trains with brakes on single shafts while the third group consists of gear trains with brakes on coupled and single shafts. The concrete characteristics of all groups are presented in [3].

The compound gear trains with brakes on single shafts (V6 and V12) is laid out in Fig. 5.

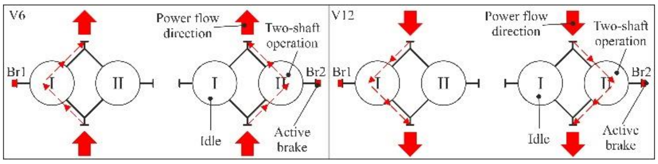


Fig. 5 *Power flows through the compound gear train with brakes on the single shafts*

All realizable variants of PGT with brakes on single shafts (layout variants V6 and V12) are symbolically laid out in Table 1. By activation of the left brake, power is transferred through the left component train (component train I), and by activation of the right brake, power is transferred through the right component train (component train II).

Input and output of the power are on the coupled shafts. In this example, regardless of brake activation, the power is actively transmitted by only one component train, while the other remains idle. Hence, the of the compound train transmission ratios are straight to the component gear trains transmission ratios. Transmission ratio ranges for both operating regimes are provided for all variants in Table 1.

The transmission ratio range of every variant in each group is determined by its specific properties. Some variants will provide reduction or multiplication in both ratios, while others will offer reduction in one ratio, and multiplication in the other ratio. Likewise, some PGTs will have different directions of revolution of the output shaft, while others will keep the same direction. The transmission ratios that can be achieved by these variants are limited only by the kinematic capabilities of their respective planetary gearsets, while the transmission ratio of each unit refers only to the ideal torque ratio of the active planetary gear unit.

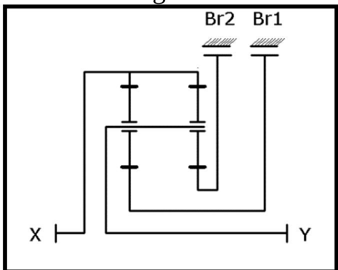
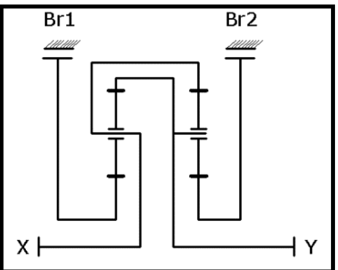
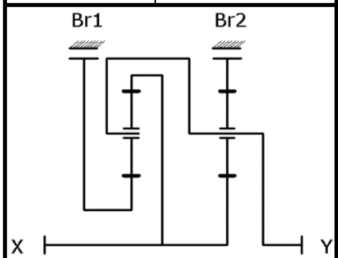
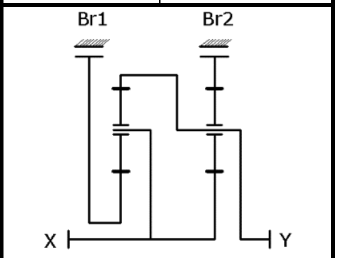
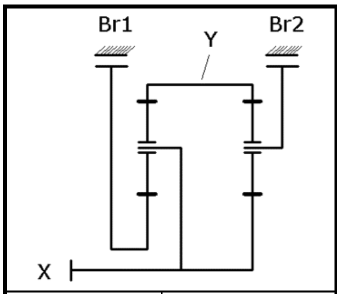
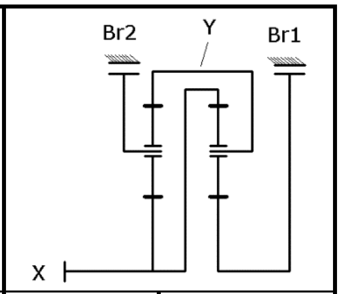
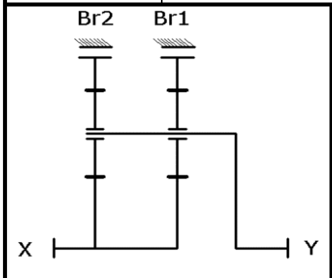
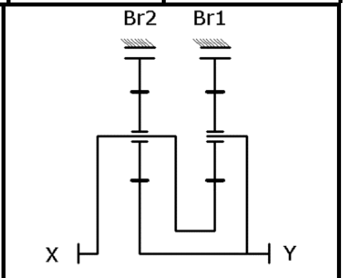
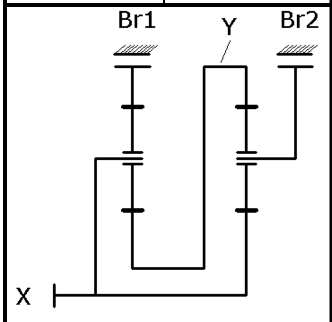
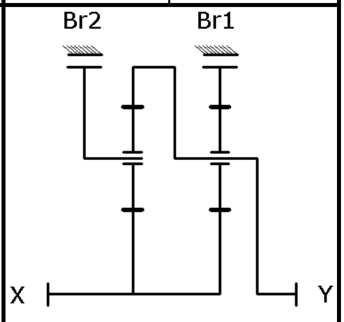
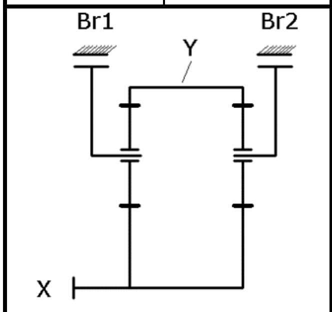
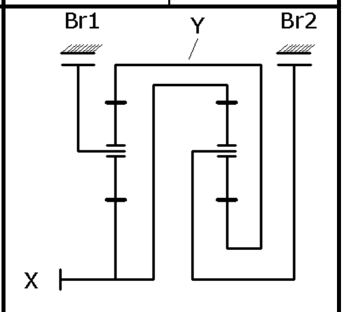
Therefore, such PGTs can provide an adequate solution if the required transmission ratios i_1 and i_2 can be achieved with a single gear unit.

All the possible kinematic schemes have been determined by means of the computer program *DVOBRZ*. As this paper deals with transmissions in which brakes are placed on single shafts, those transmissions are singled out and presented in Table 1. In addition to kinematic schemes, the transmission ratios with either brake 1 or brake 2 activated are shown. Note that brake 1 (Br1) is mounted on gearset I, while brake 2 (Br2) is mounted on gearset II. S denotes schema and V
layout variant.

Some shapes have rather inviting features, significant for determining their possible field of application. For example, layout S36V6 shifts the direction of the output member revolution by shifting the transmission ratio. Therefore, this PGT is suitable for a machine tool, which has a high load, low speed working motion, and a fast, low resistance return motion to increase productivity.

This layout also gives equal and opposite output shaft speeds with $t_{\mathrm{I}} = 1 + t_{\mathrm{II}}$.

Table 1 Design layout and kinetic features of PGTs with brakes on single shafts

			
S11V6 Power flow: $X \rightarrow Y$ $i_{Br1} \in (1{,}083...1{,}5)$ $i_{Br2} \in (1{,}083...1{,}5)$	S11V12 Power flow: $Y \rightarrow X$ $i_{Br1} \in (0{,}923...0{,}666)$ $i_{Br2} \in (0{,}923...0{,}666)$	S12V12 Power flow: $X \rightarrow Y$ $i_{Br1} \in (0{,}923...0{,}666)$ $i_{Br2} \in (1{,}083...1{,}5)$	S12V6 Power flow: $Y \rightarrow X$ $i_{Br1} \in (1{,}083...1{,}5)$ $i_{Br2} \in (0{,}923...0{,}666)$
			
S13V6 Power flow: $X \rightarrow Y$ $i_{Br1} \in (1{,}083...1{,}5)$ $i_{Br2} \in (3...13)$	S13V12 Power flow: $Y \rightarrow X$ $i_{Br1} \in (0{,}923...0{,}666)$ $i_{Br2} \in (0{,}333...0{,}077)$	S14V12 Power flow: $X \rightarrow Y$ $i_{Br1} \in (0{,}923...0{,}666)$ $i_{Br2} \in (3...13)$	S14V6 Power flow: $Y \rightarrow X$ $i_{Br1} \in (1{,}083...1{,}5)$ $i_{Br2} \in (0{,}333...0{,}077)$
			
15V12 Power flow: $X \rightarrow Y$ $i_{Br1} \in (0{,}923...0{,}666)$ $i_{Br2} \in (-2...-12)$	15V6 Power flow: $Y \rightarrow X$ $i_{Br1} \in (1{,}083...1{,}5)$ $i_{Br2} \in (-0{,}5...-0{,}083)$	16V6 Power flow: $X \rightarrow Y$ $i_{Br1} \in (1{,}083...1{,}5)$ $i_{Br2} \in (-2...-12)$	16V12 Power flow: $Y \rightarrow X$ $i_{Br1} \in (0{,}923...0{,}666)$ $i_{Br2} \in (-0{,}5...-0{,}083)$
			
S33V6 Power flow: $X \rightarrow Y$ $i_{Br1} \in (3...13)$ $i_{Br2} \in (3...13)$	S33V12 Power flow: $Y \rightarrow X$ $i_{Br1} \in (0{,}333...0{,}077)$ $i_{Br2} \in (0{,}333...0{,}077)$	S34V6 Power flow: $X \rightarrow Y$ $i_{Br1} \in (3...13)$ $i_{Br2} \in (0{,}333...0{,}077)$	S34V12 Power flow: $Y \rightarrow X$ $i_{Br1} \in (0{,}333...0{,}077)$ $i_{Br2} \in (3...13)$
			
S35V6 Power flow: $X \rightarrow Y$ $i_{Br1} \in (3...13)$ $i_{Br2} \in (-0{,}5...-0{,}083)$	S35V12 Power flow: $Y \rightarrow X$ $i_{Br1} \in (0{,}333...0{,}077)$ $i_{Br2} \in (-2...-12)$	S36V6 Power flow: $X \rightarrow Y$ $i_{Br1} \in (3...13)$ $i_{Br2} \in (-2...-12)$	S36V12 Power flow: $Y \rightarrow X$ $i_{Br1} \in (0{,}333...0{,}077)$ $i_{Br2} \in (-0{,}5...-0{,}083)$
			
S55V12 Power flow: $X \rightarrow Y$	S55V6 Power flow: $Y \rightarrow X$	S56V12 Power flow: $X \rightarrow Y$	S56V6 Power flow: $Y \rightarrow X$

$i_{Br1} \in (-2 \ldots -12)$ $i_{Br2} \in (-2 \ldots -12)$	$i_{Br1} \in (-0,5 \ldots -0,083)$ $i_{Br2} \in (-0,5 \ldots -0,083)$	$i_{Br1} \in (-2 \ldots -12)$ $i_{Br2} \in (-0,5 \ldots -0,083)$	$i_{Br1} \in (-0,5 \ldots -0,083)$ $i_{Br2} \in (-2 \ldots -12)$

Layouts S34 and S56 may be used for a transmission with inverse ratios, the ideal torque ratios $t_{I} = t_{II}$ being equal. It must be mentioned that Put's where the brakes are situated on single shafts have some design limitations.

For example, a layout using three planets per units cannot achieve transmission ratios lower than 0,0769 or greater than 13, and Put's where brakes are situated on coupled shafts or with brakes on coupled and single shafts should be considered for such cases.

5 CONCLUSION

This paper introduces the process of fast resolution of the internal structure of compound gear trains for two-speed operation. This is permitted by using the computer program *DVOBRZ,* which has been expanded for the examination of compound gear trains An acceptable solution has been provided together with kinematic schemes and symbolic view with power flow.

Further research in this area is expected to focus on two-speed planetary gear trains achieving equal transmission ratios in both directions of rotation of the output shaft, planetary gearsets that can achieve one reduction, one multiplication and one reverse gear, and finally multi-speed gearboxes composed of several two-carrier trains, especially useful when dealing with hybrid and fully electric power trains.

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SIMULATION AND ANALYSIS OF THE WHEEL LOADERS WORKING CYCLE

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Abstract

The paper defines a mathematical model of wheel loader for numerical simulation and analysis of working cycle. The results of the analysis show that the loads of the mechanisms are the largest during a material loading, and during a material transport operation, the greatest impact on the loading of the mechanisms have the gravitational force of the captured material. The results of the analysis also show that during certain sub-operations of manipulation task in working cycle of loader there are possibilities for energy recuperation that can be accumulate using hydrostatic system and return to the drive system of the machine for use in other sub-operations of the manipulation task. As an example, the results of numerical simulation using software MSC Adams are given for the wheel loader which have in mass 15.000 kg. The obtained results also represent the input for the synthesis of the drive mechanisms of the loader manipulator.

Keywords: *Wheel loader, Numerical simulation,*

1 INTRODUCTION

A wheel loaders are part of mobile machinery mainly used to load and unload bulk materials and for light excavation work. The basic function of loaders of all sizes is the cyclic transport of material which consists of the following operations: loading (digging), transport and unloading of material, and returning to the new loading position. The loading operation can be performed in different ways adapted to the type and configuration of the material being handled, where the bucket, as the basic tool of the loader mechanisms, needs to overcome certain digging resistances with an appropriate digging force.

For the numerical analysis of the loaders working cycle, general mathematical models of loader kinematic chain and mathematical models of loader manipulation tasks were defined. The purpose of the analysis is to determine the required power of the loader in individual operations of manipulation task. There are various methodolgy for a wheel loaders modeling. In paper [1] a compound closed-loop mechanism methodology is proposed to model the wheel loader manipulator kinematics for simulating the mechanism motion in a dynamic environment. For the numerical modeling purpose, the mechanism is considered as consisting of three vector loops connected by the joint angles or displacements. In paper [2] proposed integrated wheel loader simulation model includes a driver model that is designed to perform the two objectives of working and driving. In paper [3] the wheel loader simulation model consists of mechanical and hydraulic powertrain model, multi-body dynamic model and working part dynamic model. The multi-body dynamic model is simplified since the effect of pitch and roll motion of the wheel loader on the energy flow of the powertrain and hydraulic actuator systems is insignificant, a simplified planar model for the dynamic vehicle is good enough for the objective of this study. In paper [4] the wheel loader is modeled as a system with five states and three control inputs including torque converter nonlinearities.

2 MATHEMATICAL MODEL OF WHEEL LOADER

Mathematical model of a wheel loader with a general kinematic chain consisting of four-member configuration includes: the rear L_1 (Fig. 1) and the front L_2 support and movement member and the loader mechanisms with the boom L_3 and the bucket L_4. The rear and the front support and movement members are connected using a vertical rotary fifth-class joint O_2, thus forming the movement mechanism of the machine. The kinematic chain of the loader mechanisms is planar configuration. The axes of the rotary joints O_i are parallel, and the centres of the joints lies down in the same plane - the plane of the loader mechanisms. The intersection of the bucket cutting edge through the plane of the loader mechanisms represents the centre of the bucket cutting edge O_w.

The assumptions of the mathematical model of the loader kinematic chain are: (1) the support surface and the kinematic chain members of the loader are modelled using rigid bodies; (2) the first joint between the support and movement member and the loader support surface has a variable position (O_{11}, O_{12}), lies in the centre of the surface where tires meet the ground, and has the form of rotary joints whose axes represent potential (longitudinal z–z) loader rollover lines; (3) during a manipulation task, the loader is subjected to external (technological) forces - digging resistance W and gravitational forces (weights) of: members of the kinematic chain, members of the drive system, and material scooped up by the loader bucket; (4) the kinematic chain of the wheel loader is observed during the digging operation as an open-configuration chain whose final member - the bucket, is subjected to the digging resistance W in the centre of the bucket cutting edge and in the plane of the whel loader mechanisms [5].

The working area of the loader model is determined by an absolute coordinate system $OXYZ$ with unit vectors i; j; k along the coordinate axes OX, OY, and OZ. The loader support surface lies in the horizontal *OXZ* plane of the absolute coordinate system, while the vertical *OY* axis of the same system falls on the axis of the kinematic pair of the front and rear member of the support and movement mechanism.

In the final member of the chain–the bucket, the O_4x_4 axis of the local coordinate system passes through the centre of joint O_4 and the centre of the bucket cutting edge O_w. The member of the kinematic chain L_i is determined, in its local coordinate system $O_ix_iy_iz_i$, by a set of values (Fig. 1):

$$L_i = \left\{ \widehat{\boldsymbol{e}}_i, \widehat{\boldsymbol{s}}_i, \widehat{\boldsymbol{t}}_i, m_i, \widehat{\boldsymbol{J}}_i \right\} \qquad (1)$$

where: $\widehat{\boldsymbol{e}}_i$ – the unit vector of joint O_i axis which connects link L_i to the previous link L_{i-1} (Fig. 1), $\widehat{\boldsymbol{s}}_i$ – the vector of the position of joint O_{i+1} centre which is used to connect the chain link L_i to the next member L_{i+1}, $\widehat{\boldsymbol{t}}_i$ – the vector of the position of the member L_i mass centre, m_i – the link mass, $\widehat{\boldsymbol{J}}_i$ – the tensor of the moment of inertia of the link. Vector quantities marked with a ‘cap’ relate to the local coordinate system, while those without a ‘cap’ relate to the absolute coordinate system.

The wheels of the supporting-moving mechanism are the same size and determined by a set:

$$L_{1j} = \left\{ r_{dij}, m_{ij}, \boldsymbol{J}_{ij} \right\} \quad \forall\, i,j = 1,2 \qquad (2)$$

where: r_{dij} - dynamic radius of the wheel, m_{ij} - mass of the wheel, $\boldsymbol{J}_{ij}$ - moment of inertia of the wheel.

The relative (generalized) coordinates of the mathematical model of the loader kinematic chain are determined by set (Fig. 1):

$$\theta = \{ \theta_1, \theta_2, \theta_3, \theta_4 \} \qquad (3)$$

where: θ_1 - the angle of rotation of the wheels in relation to the ground, θ_2 - the angle of the relative position of the rear L_1 and the front L_2 support and movement member of the loader, θ_3 - the angle of the relative position of the boom in relation to the front support and movement member , θ_4 - the angle of the relative bucket position in relation to the boom.

The position of the L_i chain member in relation to the vertical *OXY* and horizontal *OXZ* plane of the absolute loader coordinate system is determined by the angles:

$$\varphi_1 = \theta_1 ; \varphi_2 = \theta_2 \qquad (4)$$

$$\varphi_i = \sum_{i=3}^{4} \theta_i \quad \forall\ i = 3,4 \qquad (5)$$

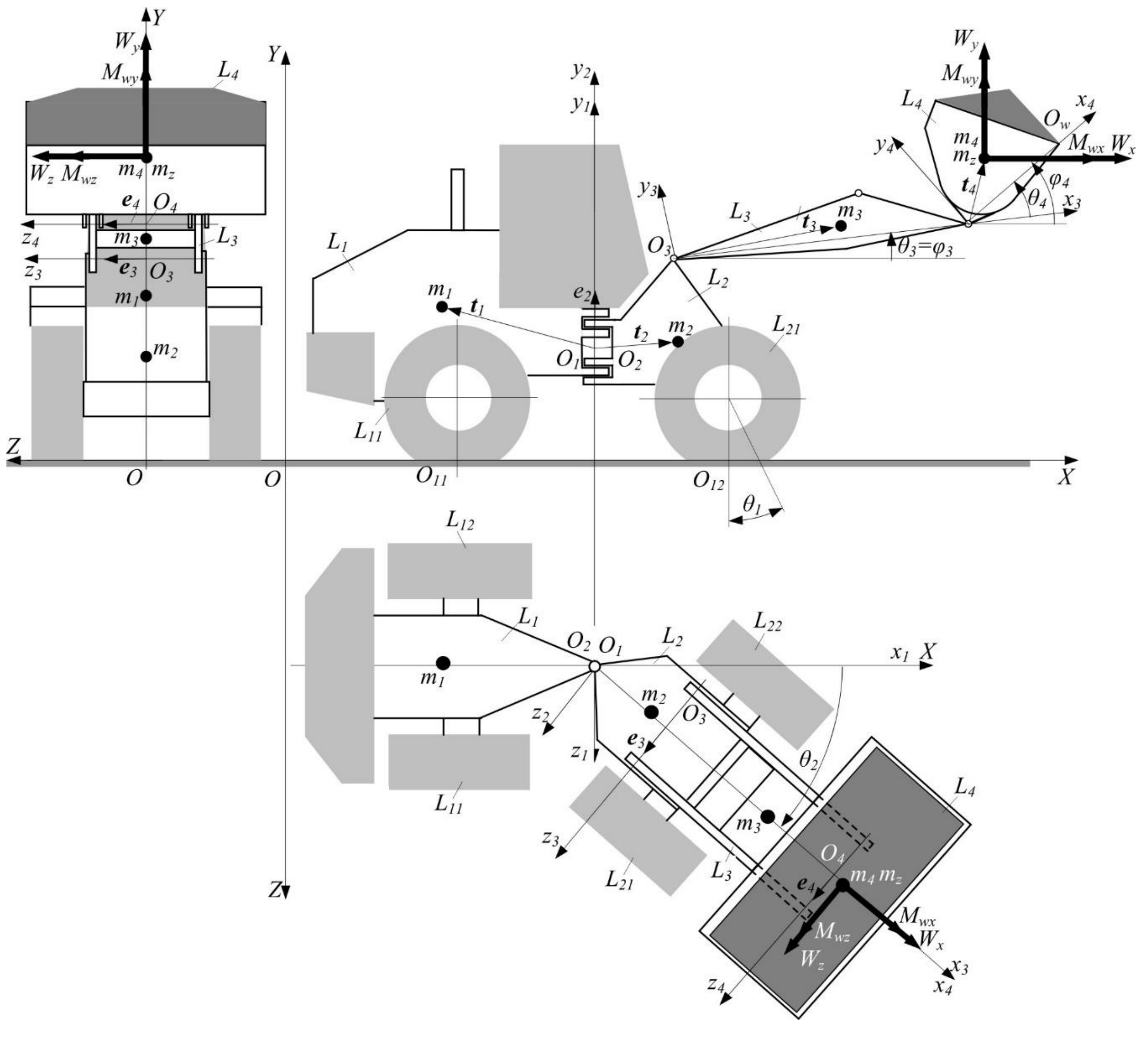

Fig. 1. *Kinematic chain of wheel loader*

By fictitiously breaking the kinematic chain of the manipulator in the joint O_i ($i=3,4$) from the equilibrium condition, the forces in the center of the joint are determined:

- resultant force:

$$\boldsymbol{F}_{ri} = \boldsymbol{F}_{gi} + \boldsymbol{F}_i + \boldsymbol{W} \ \ \forall\, i = 3,4 \tag{6}$$

- resultant moment:

$$\boldsymbol{M}_{ri} = \boldsymbol{M}_{gi} + \boldsymbol{M}_i + \boldsymbol{M}_{wm} \ \ \forall\, i = 3,4 \tag{7}$$

where: $\boldsymbol{F}_{gi}$ - resultant of gravitational forces of the kinematic chain members, $\boldsymbol{F}_i$ - resultant of inertial forces caused by the movement of the kinematic chain members, $\boldsymbol{W}$ - force of material loading resistance, $\boldsymbol{M}_{gi}$ - resulting moment of gravitational forces, $\boldsymbol{M}_i$ - resulting moment of inertia caused by movements of the kinematic chain members, $\boldsymbol{M}_{wm}$ - moment of resistance when material is loading.
Loading moments of loader manipulator drive mechanisms:

$$\boldsymbol{M}_{oi} = \boldsymbol{M}_{ri} \cdot \boldsymbol{e}_i \quad \forall \quad i = 3,4 \tag{8}$$

where: $\boldsymbol{e}_i$ - unit vector of the joint axis of the executive member of the drive mechanism.

2.1. Models of manipulation task

The models of manipulation task represent the input of the numerical simulation of the loader, which depend on the parameters: working conditions and working objects of the loader. In general, the working conditions refer to the environment in which the machine moves and performs its functions, and the parameters of the working objects are the characteristics of the materials that the machine transfers.
For the numerical simulation of the loader operation, the selected parameters of the working conditions and the subject of work are included in the set of quantities:

$$U_p = \{\alpha_p, \mu_p, U_m\} \tag{9}$$

where: α_p - the slop angle of the base during the operation task, μ_p - the coefficient of adhesion of the wheels and the base support, U_m - a subset of the characteristics of the transferred material.
For the numerical simulation of the loader, manipulation tasks models were developed for the primary function of the loader - cyclic material transport with a bucket-shaped tool.
Manipulation tasks models are determined by the sub-operation parameters of the loader cyclic work. The basics sub-operation of the cyclic manipulation task are: loading, transport and unloading of materials.
Research [6] [7] related to the efficiency of loader work shows that the basic sub-operation (loading) of the manipulation task are performed in different ways. According to the results of the conducted research, the method of carrying out the loading sub-operation depends, among other things, on the type of material, working conditions (whether the material is in an unlimited or limited space) and the machine operator skills. The material transport sub-operation depends significantly on the relative position of the loading and unloading sites. However, for the planning of works with more voluminous material in an unlimited area of the loading point and a certain position of the material unloading point, the paths of the material transport operation have the shape of the latin letter *V* or *Y*. Typical *V* and *Y* paths of the material transfer consists from connected sections of the back movement of the loader with full bucket from the point of loading and part of the forward movement path of the loader with a full bucket towards the place of material unloading. The unloading operation is usually carried out in a special transport place or a place with limited or unlimited space.
Examples of numerical loader simulation are given for three manipulation tasks with different loading methods: linear, stepped and parabolic.

- In the first linear method of materials loading (Fig. 2a) the bucket is lowered - on the surface, by movement of the loader, bucket horizontally penetrates the materials. At the end of movement of the machine, bucket is loading by rotation around the joint *O4* on the top of the boom, until the bucket exit from the material.
- Second method (II) (Fig. 2b) of bucket penetration, is realized with two shorter oexvperations of the first method, but on two different height in the material.
- Third method (III) with the parabolic trajectory (Fig. 2c) of bucket pentration is achieved with a simultaneously movement of loaders, boom lifting and bucket rotatation.

Researches [8] [9] have shown that loader operators most often use the first method of material loading with a straight path of bucket penetration due to the easy way to control the machine because the machine movement commands and the bucket rotation commands are separated and their activation is not simultaneous. Disadvantages of this method of loading are increased movement resistance and material spillage when filling the bucket.

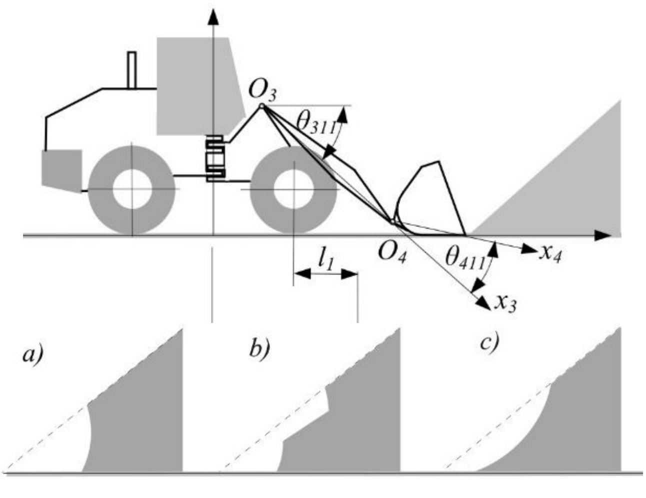

Fig. 2. *Manipulation task of loader: a) linear, b) stepped and c) parabolic path of penetration of the bucket edge into the mass of material*

The results of the same research show that the highest energy efficiency of the loader is achieved by the method of parabolic material loading. The disadvantage of this method of loading is that it is difficult to handle because it is necessary to activate three controls of the control system at the same time. The results of the research indicate that the disadvantages of parabolic loading will be eliminated by automating the operation of the loader.

2.2. Determination of resistance force

The resistance force during all sub-operations of the loader manipulation task is modeled by the components W_x, W_y, W_z of the resistance force vector and the components M_{wx}, M_{wy}, M_{wz} of the vector of moments of resistance during material loading, which act oriented along the axes of the loader's absolute coordinate system and act at the center of the mass of the bucket.

The digging resistances during material loading were determined using the descrete element method *DEM*. The *DEM* software is used to analyze the diging resistance of granular materials of different characteristics in intermittent and continuous transport systems.

DEM is a numerical method used to predict the motion and collision of spherical particles during transport. The calculation is performed in discrete time steps. Between each time step the particles move along the straight line based on the calculated speeds and acceleration at that time step. These trajectories are used to calculate the positions (spatial coordinates) of the particles in the next time step. Particle overlaps (contacts) are used to calculate the forces acting on each particle, which determines their speeds and acceleration for each particle in the next discrete time step.

The force and moment acting on a particle represent the sum of all forces and moments that act on a particle which involves gravitational force and the compresive force of the material Eq. (11) and Eq (12).

$$m_i = \frac{dv_i}{dt} = F_{ij}^n + F_{ij}^t + m_i g \qquad (11)$$

$$I_i = \frac{d\omega_i}{dt} = R_i \times R_{ij}^t - \tau_{ij}^r \qquad (12)$$

where: m_i - the mass of the particle, I_i - the particle moment of inertia, v_i - the translation velocity of the particle, ω_i - rotation velocity of the particle, F_{ij}^n, F_{ij}^t - normal and tangential forces that occur due to the contact between the particle i and particle j at the current time step (Fig. 3), R_i - vector that begin form the centar of the particle and is directed in the direction of the acting force F_{ij}^t.

Based on the contact model (Fig. 3), the normal and tangential force are:

$$F_{ij}^n = (-k_n \delta_{ij}^n - \eta_n v_{ij}^n) \qquad (13)$$

$$F_{ij}^t = (-k_t \delta_{ij}^t - \eta_t v_{ij}^s) \qquad (14)$$

where: k_n, k_t - the elasticity coefficients in the normal and the tangential direction, η_n, η_t - the damping coefficient, $\delta_{ij}^n, \delta_{ij}^t$ - the displacement of the particle in the normal and tangential direction due to the action of the normal and tangential force, v_{ij}^n - relative velocity in normal direction, v_{ij}^s - slip velocity on the contact surface.

3 RESULTS OF SIMULATION

The parameters of the simulation conditions were determined on the basis of the analysis of the manipulation tasks of the loader which have in mass *15000 kg*, during the cyclic transport of granular material in operational conditions. The analysis includes tasks involving the loading material in an unlimited area and transfer along a *V* path on a flat horizontal surface with unloading point.

For simulation of the loading sub-operation there are used software *EDEM* which is based on discrete element method. Models of loading sub-operation are with different capture paths of the same material. From the menu of the *EDEM* software, a mass of granular material was selected, which size was generated by a normal distribution with the highest percentage of size particle was *61,5 mm*, ranging from *51,5* to *71,5 mm*, which makes a mass of material with a volume of about *300* m^3 on a horizontal surface with a angle of inclination $\varphi_m=50^o$.

Also, from the menu of the *EDEM* software, material characteristics and coefficients of interaction with the bucket made of steel sheets were adopted which reflect the most common work technologies, but also the mass and volume of the bucket, i.e. the stability conditions of the simulated loader model.

3.1 Resistance force simulation

Resistances are determined by vectors of the resistance force W_i (Fig. 3 a,b) and the moment of resistance M_{wi} (Fig. 4 a, b) in the coordinate system with the coordinate origin at the bucket center of mass and the coordinate axes parallel to the axes of the absolute coordinate system of the set mathematical model of the loader. The obtained results show that the components W_{xi}, W_{yi}, W_{zi} of the resistance force vector W_i are very different in intensity and character of change during the manipulation tasks.

The highest intensity has the components W_{xi}, W_{yi} of the loading resistance forces that act during different operations of the material loading in the direction of the *OX* and *OY* axes of the absolute coordinate system of the loader, while the components W_{zi} in the direction of the *OZ* axis have insignificant values. The changes in components W_{xi} and W_{yi} depends on the method of the material loading. In the first (I) loading method, in the phase of accelerated movement of the machine, i.e. accelerated horizontal penetration of the bucket into the mass of material, the components W_{xI} and W_{yI} of the resistance forces gradually increase, and in the stopping phase of the movement of the machine they gradually decrease without significant sudden changes.

In the second (II) loading method, the W_{xII} and W_{yII} components have very suddenly changes due to the intermittent and stepwise penetration of the bucket into the mass of material. A characteristic change occurred when (*t=5s*) the W_{yII} component suddenly decreased and the W_{xII} component suddenly increased. Such a change occurred due to the horizontal penetration of the bucket at maximum speed without its closing rotation at the beginning of the second level of material capture.

In the third (III) method of material loading, the W_{xIII} and W_{yIII} components have sharp changes. The first such change appeared at the beginning of the manipulation task (*t=1.5-2 s*) when the bucket at the maximum penetration speed exerted pressure on the material so that, apart from component W_{xIII}, which acts in the negative direction of the *OX* axis, the component W_{yIII}, which acts in the positive direction of the *OY* axis, appeared as a reaction of the pressed material outside the bucket. The second characteristic change occurred (*t=3s*) when the W_{xIII} and W_{yIII} components reached their highest intensities, which were caused by the maximum horizontal speed of the bucket penetration while simultaneously raising the boom and closing the bucket.

During material transport operations (*t=7-20 s*), the components of the force that act on bucket from loaded material, have insignificantly small values.

The obtained results show (Fig. 4 a, b) that the components of moments M_{wi} of resistance have very different intensities and character of change during operation tasks. The components M_{wzi} of the resistance moment acting around the *OZ* axis during loading operations (*t=0-8 s*) have the greatest intensity, with the character of changes, depending on the method of the material loading, similar to changes in the components W_{xi} and W_{yi} of the loading resistance forces. The frequency of changes of low intensity of the components M_{wxi} and M_{wyi} of the resistance moments occurs during the loading operations (*t=2-4 s*) due to the action of the components W_{zi} *(Fig. 3b*) of the forces that occur due to the interaction of the granules of the captured material when the bucket is loading.

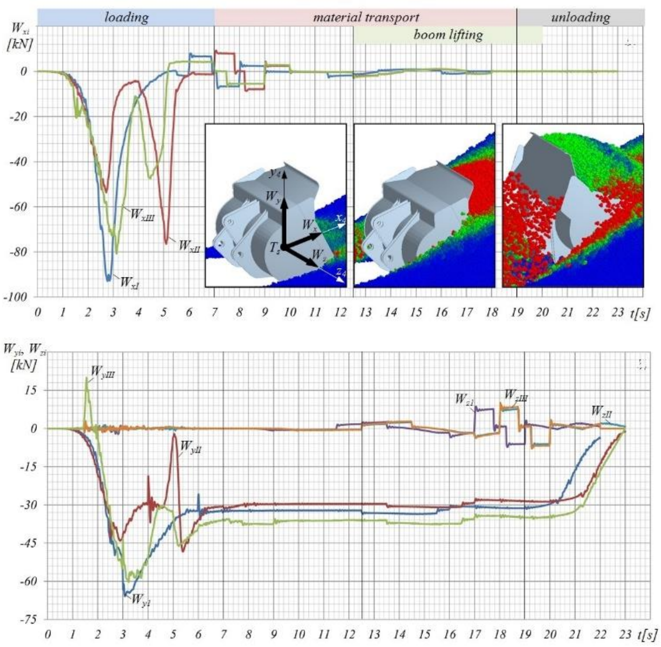

Fig. 3. *Components W_{xi} (a) W_{yi} and W_{zi} (b) of the resistance force vector of linear (I), stepped (II) and parabolic (III) loading method*

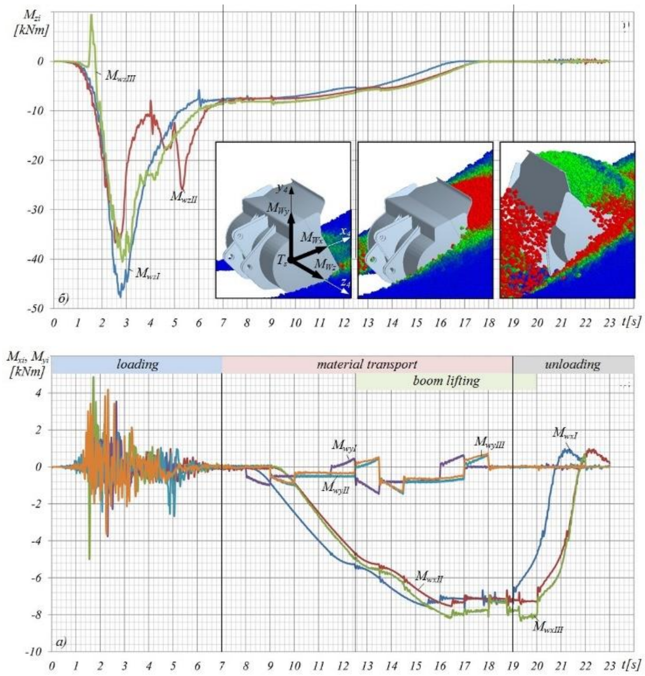

Fig. 4. *Components M_{wzi} (a), M_{wxi} and M_{wyi} (b) of moments of resistance force of linear (I), stepped (II) and parabolic (III) loading method*

3.2 Kinematics of kinematic chain members

Based on the limit initial/end positions ($\theta_{ij1}/\theta_{ij4}$) and movement time ($t_{ij1}/t_{ij4}$) of the members of the kinematic chain during each operation, the change in generalized coordinates (θ_1, θ_2, θ_3, θ_4) was determined (Fig. 5) of the relative position and velocity (Fig. 6) of the relative movement of the members of the loaders kinematic chain depending on the duration of the manipulation task.

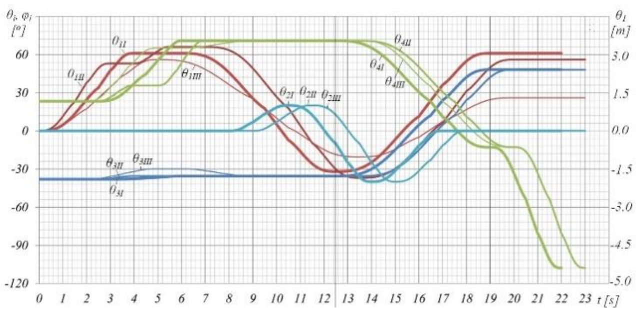

Fig. 5. *Generalized coordinates of the members of loaders kinematic chain*

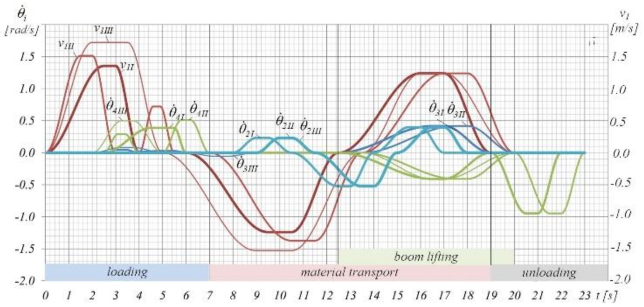

Fig. 6. *Velocity of the members of loaders kinematic chain*

3.3. Loads of manipulator drive mechanisms

Based on the parameters of the kinematic chain of the loader mathematical model and obtained results of movement kinematics and movement resistance, using the MSC Adams software, according to equation 8, the load moments M_{o3} and M_{o4} (Fig. 7 and Fig. 8) of the boom and bucket drive mechanisms were determined. The load moment M_{o3} of the drive mechanism of the boom L_3 acts around the O_3z_3 axis of the joint O_3, which connects the boom to the first member of the L_2 support-moving mechanism. The load moment M_{o4} of the driving mechanism of the bucket L_4 acts around the axis O_4z_4 of the pivot joint O_4 by which the bucket is attached to the tip of the boom L_3.

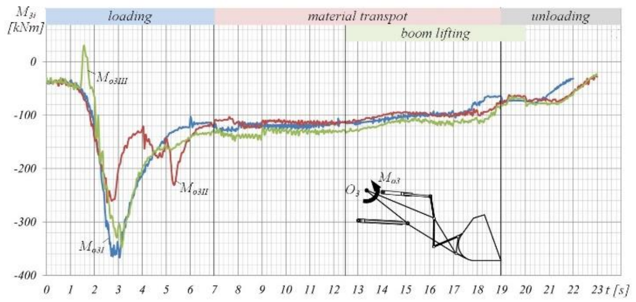

Fig. 7. *Load moment of boom drive mechanism of linear (I), stepped (II) and parabolic (III) loading method*

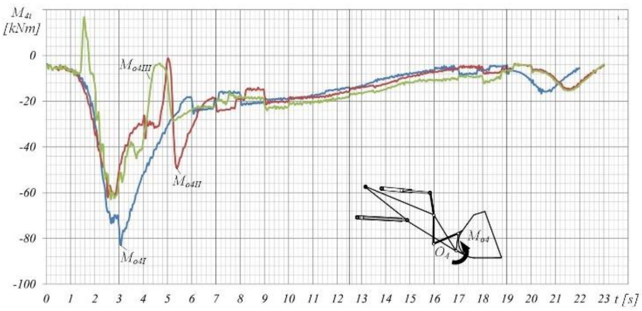

Fig. 8. *Load moment of bucket drive mechanism of linear (I), stepped (II) and parabolic (III) loading method*

During operation task, the load moments of the mechanism are the highest during loading sub-operation (t=0-8 s). The nature of their change depends on the way the material is loaded, on the forces and moments of loading resistances that occur [15].

CONCLUSION

Using the developed procedure of loader simulation, research was carried out with the aim of determining the type, intensity and character of the load change of the manipulator's drive mechanisms during the operation task of the loader, the impact of the load from the resistance of the loaded material on the load on the mechanisms, importance and size of kinematic, dynamic and energy parameters of individual operations of the manipulation task of the loader required for the synthesis of the drive mechanisms of the manipulator.

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UNIVERSITY OF NIS FACULTY OF MECHANICAL ENGINEERING

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EFFICIENCY COMPARISON OF LINE BELT SORTER AND AGV ROBOTS SORTER

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Abstract

Material flow simulation is a very effective way to determine the feasibility of any complex transport system such as a sorter and to test its parameters. This paper present the calculation of the sorter performance for two different types of sorters (belt and agv sorters) and then simulates the entire sorting process and material flow in AutoMOD with the same basic parameters, but with all the complexity due to the differences in the sorters. After the analysis of the simulation data, their comparison and some proposed optimizations are given.

Key words*: materialflow, sorter, simulation, efficiency, optimization.*

1 INTRODUCTION

The simulation is used to analyze material flow real problems in transport and logistics and to detect possible traffic jams or stoppage points. That is why a simulation experiment is carried out with the help of adequate software.

The essence of modeling the real process in a production or storage system is the process of displaying a previously known initial conditions. In addition to modeling the virtual environment, precise definition of the input parameters is also necessary. After that, the goal of the simulation experiment itself should be determined.
After downloading all the necessary parameters for defining the working environment, a further systematic analysis of the flow of transport and logistics processes is approached. Model development consists of defining an identical state in the logistics process and imitating real processes in real time when performing all activities in the system.

After mapping the real process in the modeling, the simulation is approached. Performing a simulation provides different useful data that can be used for different purposes depending on the function of the goal of the simulation. The simulation is often carried out before the equipment is arranged in the hall in order to arrange the machines as well as possible and define the transport routes according to the goals.
A number of simulation software can be used to simulate processes and materialflow in companies. In this paper to simulate the sorting systems will be used simulation software AutoMOD [1]. This software can be applied to various optimization problems [2, 3, 4, 5].
The application of conveying systems in real time based on simulation in one production environment can be seen in papers [7, 8, 9, 10, 11].

2 SORTER TYPES

In this paper there are two different sorter types to be analyzed and compared. First will be presented line belt sorter and then agv robots sorter i.e. using automated guided vehicles (AGVs) for sorting.
Theoretical calculations and simulation data will be compared and analyzed.
It assumed equal space for sorting (14 x 6 m), and there is one sorter feeding point (qIn) with manual feeding by on man, and eight sorting exit points (qOut1 – qOut8) for delivering loads (parcells) according to customer orders.

2.1 Belt sorter

Belt width is b = 1 [m] and belt sorter speed is v = 1 [m/s]. The belt sorter layout is shown in Fig.1.

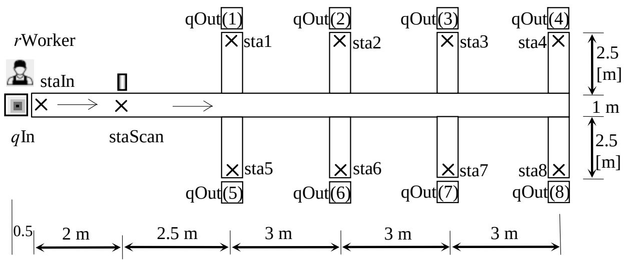

Fig. 1 *Layout of Belt Sorter*

Sorting duration is 1 hour. Feeding of loads on belt sorter is manual, by one worker (rWorker), from load source (qIn) to the entrance point on the belt (staIn), and it correspond to normal distribution of feeding time with mean of 3 [s] and standard deviation of 0.5 [s]. After traveling for some time on the belt conveyor, the load stops for 1 [s] at the scanning point (staScan), where every load will be assigned to the exact delivering destination, then loads continue traveling to predefined endpoint, where parcels are collecting for shipping to the customers. Load distribution in [%] per eight endpoints (qOut1 – qOut8) is shown in Table 1.

Table 1 Number of Loads - NoL [in %] per sorter outputs

qOut	1	2	3	4	5	6	7	8
NoL [%]	***12***	***13***	***15***	***11***	***16***	***10***	***14***	***9***

The optimal load transportation tact is 3 [s], equal to the same sorter feeding time.
The maximal theoretical capacity would be then:

$$Q_{\max} = 3600 \cdot v / t_{tact} = 3600 \cdot 1/3 = 1200 [loads/hour]$$

That theoretical capacity is usually difficult to achieve in real conditions, depending on the sorting parameters.
The belt sorter simulation, with these conditions, was executed in AutoMOD. The frozen view of sorting process at the end of simulation, after 1 hour, is shown in Fig.2.

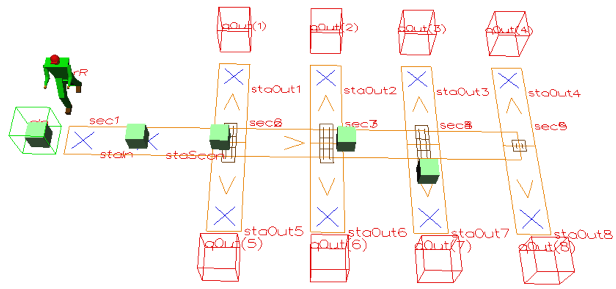

Fig. 2 *The frozen view at the end of belt sorter simulation*

The duration of simulations is 1 [h], the same as all the other listed parameters. AutoMOD simulation shows that 1192 parcels were delivered in 1 hour time and four loads more were in that moment in the delivery phase, travelling on belt sorter (Fig.2).
Utilization of the feeding worker is close to 99.9% and his average working time is 3.0 [s]. Number of loads delivered to all 8 outputs for 1 hour is shown in Table 2.

Table 2 Number of Loads (NoL) per outputs for line belt sorter by AutoMOD

qOut	Total loads	NoL [%]	Difference [%]
1	158	13.26	1.26
2	155	13.00	0.00
3	172	14.43	0.57
4	142	11.91	0.91
5	186	15.60	0.40
6	113	9.48	0.52
7	176	14.76	0.76
8	90	7.56	1.44
Σ	**1192**	**100**	/

Simulated data and theoretical numbers shows very small difference in numbers of loads, less than 6.7%. It means that simulation confirms calculation.
Under these sorting circumstances, applying a higher belt speed or reducing the scanning time would increase the number of sorted loads by only a few parcels. The only effective solution would be to reduce the feeding time or to include two workers at the sorters feeding point and then a higher belt speed could be manifested in a higher efficiency of the sorter.
Scanning times would play a great role only if there are enough loads at the input of the sorter and if the belt speed is higher. Today, automated sorting and conveying systems can accurately scan the barcode in motion so there is no need to stop the loads.
The simulation presentation (Fig.2) does not represent real shapes of sorter and loads (parcels), because the goal was not to have visual fidelity but reliable simulation data.

2.2 AGV robots sorter

Number of automated guided vehicles (AGV) for sorting is defined as Z = 8, and corresponds to number of sorter endpoints, which means that there is one vehicle for each exit point. AGVs speed is set to v = 1 [m/s], and it is equal to the belt sorter speed in the previous case.
AGVs sorter layout with all defined paths (dashed lines) and directions is shown in Fig.3. There are three one way paths for AGVs movement, two paths (outside) for delivering and one path (inside) for retrieving movements of AGVs.

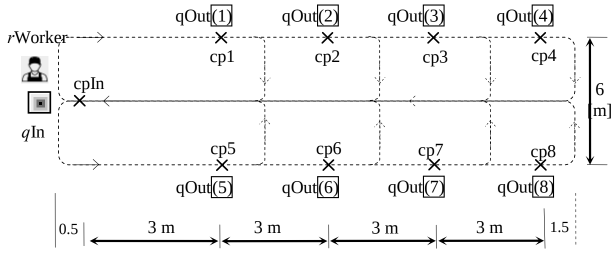

Fig. 3 *Layout of AGV sorter*

Duration of sorting simulations is also 1 [h]. Feeding of loads on AGV's is also manual, by one worker (rWorker), from load source (qIn) to feed point (cpIn), and it correspond to normal distribution of feeding time with mean of 3 [s] and standard deviation of 0.5 [s]. During the feeding of AGVs scanning is underway. AGVs then move to one of eight endpoints and after reaching the defined destination, it take 1 [s] of time to unload every AGV. Load distribution in [%] per all eight endpoints (qOut1 – qOut8) is the same as previous (see Table 1).

Fig. 4 *Tilt tray AGV robot when unloading*

Automated Guided Vehicles (AGVs) have a folding tilt tray mechanism that serves them for unloading (Fig.4). Tompkins robotics AGV tilt tray robots have the speed is up to 2.5 [m/s] and the load capacity from 5 to 15 [kg].

Theoretical median cycle time of an AGV vehicle is:

$$t_c(AGV) = t_{load} + +t_{unload} + \frac{L_m}{v}$$

$$t_c(AGV) = 3 + 1 + \frac{25}{1} = 29\,[s] = 0.483\,[\min] \approx 0.5\,[\min]$$

where accelerations and decelerations times of vehicles are disregarded. The mean moving distance for AGVs is:

$$L_m = L_{deliv+retriv} = (L_1 + L_2 + L_3 + L_4)/4 \approx 25\,[m], \text{ or:}$$

$$L_m = L_{deliv+retriv} = (L_5 + L_6 + L_7 + L_8)/4 \approx 25\,[m]$$

If we calculate load distribution to every exit point (Table 1), then the mean moving distance for AGVs is:

$$L_m = (0.12 \cdot L_1 + 0.13 \cdot L_2 + 0.15 \cdot L_3 + 0.11 \cdot L_4 + \\ + 0.16 \cdot L_5 + 0.1 \cdot L_6 + 0.14 \cdot L_7 + 0.09 \cdot L_8) = 24.7\,[m]$$

so there is very small difference in cycle time value:

$$t_c(AGV) = 3 + 1 + \frac{24.7}{1} = 28.7\,[s] = 0.478\,[\min] \approx 0.5\,[\min]$$

Number of cycles per each AGV is:

$$n_c = 1/t_c(AGV) = 1/0.5 = 2\,[cycles/\min] = 120\,[cycles/hour]$$

It means that one AGV vehicle will transport approximately N = 120 loads in 1 hour (exactly 125 loads), i.e. eight AGVs will deliver about N = 960 loads in 1 hour time, theoretically calculated.
The AGV sorter simulation, with the same conditions, was done in AutoMOD. The frozen view of sorting process at the end of simulation, after 1 hour, is shown in Fig. 4.

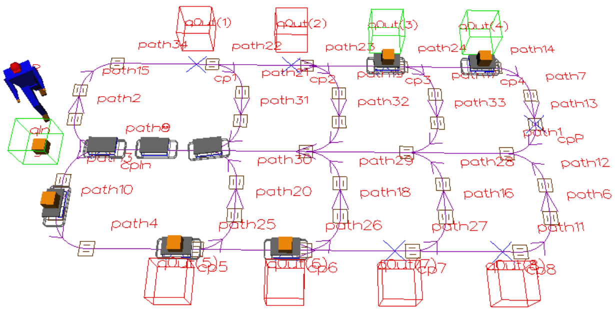

***Fig. 4** The frozen view at the end of simulation with Z=8 AGVs*

The simulation view does not represent the real shapes of AGVs and loads (parcels), because the goal was not to have visual fidelity but reliable simulation data.
Simulation displays that N = 802 parcels were delivered in 1 hour time and an additional five loads were in that moment in the delivery phase, on AGVs .
Utilization of the feeding worker is 67.3% and his average working time is 2.98 [s]. The number of loads delivered to all 8 outputs for 1 hour is shown in Table 3.
Simulation data shows ΔN = 158 loads less delivered than theoretically calculated. This can be explained by reduced speed of movement in curves, by additional time for acceleration and deceleration of AGVs at feeding and unloading points and by traffic jam.

Table 3 The number of Loads (NoL) per outputs for AGV robots sorter by AutoMOD

qOut	Total loads	NoL [%]	Difference [%]
1	96	11.97	0.03
2	103	12.84	0.16
3	111	13.84	1.16
4	89	11.10	0.10
5	135	16.83	0.83
6	83	10.35	0.35
7	115	14.34	0.34
8	70	8.73	0.27
Σ	**802**	**100**	/

In comparasion to a belt sorter, when sorting using robots there is no time for scanning loads, because the scanning process takes place parallel with feeding the vehicles. But there is a extra time of 1 sec for unloading of AGVs at exit points (Fig.4), what includes AGV positioning and tray tilting time.
So the defined time equivalent is approximately the same in both sorters examples, as well as distances.
There are some small differences between predefined number of loads per exit points (Table 1) and the simulated number of loads (Table 3), because for each simulation software exist its own random number generator type and therefore real numbers always deviate from theoretical data.
If set Z_a = 9 AGVs, with the same all other parameters, AutoMOD simulation shows that number of delivered loads is N = 822, plus there are 4 loads currently in the delivery process on AGVs. It means that only ΔN = 20 loads more were sorted in comparation to the previous simulation (with Z = 8 AGVs).
By adding one more AGV in simulation (Z_b =10), there are only two more loads sorted for one hour i.e. there is N = 824 loads delivered to one of eight endpoints, plus 3 loads currently in the delivery process on AGVs. It means that adding more AGVs in the sorting process does not contribute to the larger number of sorted loads.
On the other hand, by reducing the number of AGV rorots to Z_c = 7, the simulation shows only N = 743 loads distributed. It is a significant decrease of ΔN = 59 loads, in comparasion with a predefined number of Z = 8 AGVs.
All four simulations data shows, that the optimal number of AGVs here is Z = 8, as initially assumed.

2.3 Comparison of the sorters performance

Calculated numbers of sorted loads and simulated data for line belt sorter are approximately equal, there is very smal diffference. But there is a big difference between theoretical and simulated data for AGV robots sorting. The simulated number of sorted items deliveries was only 83% in comparasion to the theoretically calculated number of loads. The explanation for this comes down to a simplified calculation procedure and because of traffic jams of AGVs during theirs movement.
This paper shows the need for the simulation of complex transport and logistics systems in order to know reliable data and make correct conclusions.

Belt line sorter delivers significantly more loads than AGV robots sorter, with approximately the same conditions and parameters.

Calculated numbers shows that the number of sorted loads is almost 25% higher by belt sorter than by AGVs, but simulated data shows an increase in a sorted items by belt sorter for almost 50% in comparasion to AGVs sorting.

There is also a need for charging AGVs, lasting from 5 to 8 min on every 3 to 4 hours of utilization, and that fact also reduces the efficiency of AGVs sorting. Also every AGV on charging can be replaced with another one, but it increases the cost of the sorting system.

Line belt conveyors sorters have greater speed range up to four times than AGV robots, and this makes them much more effective for real sorting applications.

3 CONCLUSION

Belt sorters are fare more efficient then AGV robots sorters, also belt sorters have simpler construction than AGV systems.

All line sorters are generally simpler and therefore belt sorters are cheaper than AGV systems, they have fewer sensors and equipment for automatisation. It means that maintenance of belt sorters is also cheaper and in both case studies there is only one worker needed for realization of the sorting process.

As the analyses were performed for the same conditions and in an equal space, it can be concluded that in these circumstances, the belt line sorter is a much better solution for use than AGV robot sorter, in terms of performance and when it comes to price and maintenance.

Line belt sorters are recommended for use when it is necessary to sort a large number of loads for a smaller number of users, like in postal parcel services etc.

AGV robot sorter systems could be more suitable for use when there is a small number of loads to be sorted per user, for a large number of different users and where is a great variety of sorting, like online shopping etc.

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TRAFFIC ENGINEERING, URBAN MOBILITY

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TRANSPORT AND LOGISTICS

til 2023

TOWARDS A PAN-EUROPEAN INNOVATION MOBILITY NETWORK: BRIDGING SME NEEDS AND INNOVATION SUPPORT OFFERINGS

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Abstract

In the dynamically evolving landscape of mobility innovation, Small and Medium-sized Enterprises (SMEs) are recognized as pivotal agents of change and essential drivers of progress. The extent of their impact hinges on their ability to innovate and adapt. Clusters and networks play a crucial role in facilitating this transformative journey. Despite ongoing initiatives, the current state of play indicates there is ample room for improvement. This paper aims to simultaneously explore the unique needs and aspirations of SMEs operating within the European mobility sector and evaluate the offerings of innovation support providers. It synthesizes insights from existing sources, including European Commission's reports, as well as findings from our recent survey conducted within the European mobility ecosystem. The paper presents research findings and lays the foundation for the establishment of a Pan-European Innovation Mobility Network

Keywords: Mobility, SMEs, clusters, innovation support

1 INTRODUCTION

The mobility sector is widely recognized as a cradle of innovation. According to the European Commission's (ECs) priority report [1] the yearly global turnover of the Mobility Technologies emerging industry (i.e. development, manufacturing, maintenance and core services) was assessed between 2 000 and 2 150 billion Euros in 2017. As the automotive industry embraces a broader concept of mobility, it is experiencing a significant transformation. This shift is primarily fuelled by the convergence of four major trends known as ACES: autonomous driving, connected vehicles, electrified transportation, and smart mobility. It is estimated that securing a strong position across all four areas would cost a single player an $70 billion through 2030. [2] Automotive Original Equipment Manufacturers (OEMs), suppliers, as well as newcomers like technology companies and venture capitalists, are actively seeking to establish a strong presence within the emerging mobility ecosystem. Although much effort is put to make Small and Medium-sized Enterprises (SMEs) and startups play a pivotal role in mobility innovation, they are still contending with this path of development.

Across the globe, governments and various organizations are fronting initiatives to equip SMEs with the requisite support for fostering innovation and adaptability. Besides different funding opportunities networks and clusters of mobility stakeholders are recognized as a key supporter on the path of innovation. They create a collaborative ecosystem where diverse stakeholders come together to innovate, share resources, reduce risks, and access markets and policy influence [3]. This collaborative environment is vital for driving innovation in the rapidly evolving mobility sector. As highlighted in [4] and [3] companies tap "networks of inventors, scientists, and suppliers" and even competitors in their innovation efforts. Namely, as the borderline between a company and its external surroundings becomes increasingly permeable, firms are proactively extending their outreach to strengthen their capacity for innovation generation.

Sources related to the specific needs of Small and Medium-sized Enterprises (SMEs) in the mobility and transport sector, particularly in the context of innovation, are notably scarce. This information is often embedded within broader reports, where it constitutes only a minor portion of the content. Few reports are thematically dedicated to addressing the unique requirements of SMEs in this sector. This limited availability of dedicated sources and thematic coverage poses challenges in formulating well-informed decisions and designing effective support mechanisms for enhancing SME support in the mobility and transport sector. Consequently, there is an urgent need to establish a comprehensive support mechanism aimed at fostering synergies and elevating the existing support structures, both within and beyond the mobility ecosystem. This would ultimately lead to the creation of a more resilient and responsive environment for SME innovation and growth. This paper addresses this gap by providing valuable insights drawn from existing sources, as well as from a recent survey-based approach conducted among SMEs and innovation support providers operating within the European mobility ecosystem. Gathered insights are used to set basics for the establishment of the pan-European Mobility Innovation Network – MIN.

The paper is structured into five main sections. The subsequent section provides an overview of the innovation challenges encountered by SMEs in the mobility sector, progressing from general insights to a more in-depth analysis based on a recent survey conducted across Europe. The fourth section mirrors this approach but shifts the focus to the offerings of innovation support organizations. In the concluding section, the research findings are deliberated upon, offering perspectives on the conceptual and operational foundations for the establishment of a pan-European Mobility Innovation Network

2 INNOVATION CHALLENGES FACED BY SMEs IN MOBILITY SECTOR

2.1. Pre-scanning: insights from EC reports

According to the Annual Report on European SMEs 2021/2022 [5], the mobility (transport and storage) sector accounted for 5.3% of the overall distribution in the NBFS (Non-Banking Financial Services) industries. The same source also indicates that in 2021, SMEs contributed 43.4% to the value added, with an employment share of 52.4% in the transport and storage domain.

The European industrial strategy [6] gives special attention to supporting SMEs, which are the backbone of the European economy, and focuses on the structure and dynamics of 14 industrial ecosystems, including 'mobility - transport – automotive' (production of motor vehicles, ships, and trains, along with their accessories; their repair and maintenance). The major shift in the underlying paradigm is from growth-oriented policies to goal-based policy, cantered around the SDGs (Sustainable Development Goals) and the objective of achieving climate neutrality by 2050, later coupled with a resounding commitment to cut 55% of emissions by 2030, as outlined in the EU's Green Deal. [7] This poses additional pressure to the mobility ecosystem, The 2021-2022 survey of SME associations [5] found that 'mobility, transport and automotive' ecosystem is highly challenged by meeting the 2030 emissions target. Nearly 70% of mobility SMEs see this as impossibly or very challenging (Figure 1).

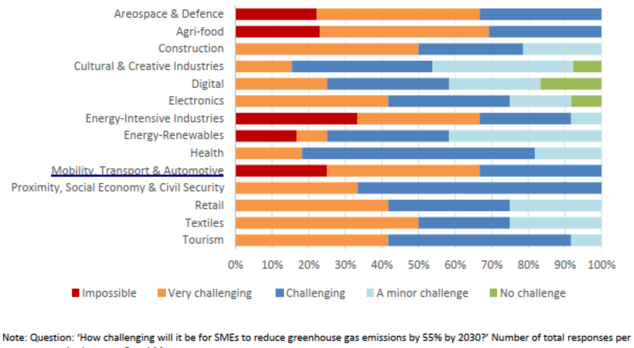

Figure 1 *Challenge of reaching the 2030 emission target as perceived by SMEs [5, p.93]*

Nourishing the contribution of SMEs to both growth and sustainability goals calls for ancillary actions to overcome compound challenges they face. Governments and institutions worldwide have initiated programs to provide essential support to SMEs. One of the central initiatives at the EU level is the 'Innovation in SMEs' program (INNOSUP), launched within the framework of Horizon 2020. To date, it has supported approximately 200 projects with a total budget of 160 million EUR. According to the 'Study on the Effectiveness of Public Innovation Support for SMEs in Europe [8], published by the EC in 2021, SMEs continue to confront innovation barriers, with those in Southern and Eastern Europe facing more significant challenges than their counterparts in Northern and Central Europe. The nature of these barriers varies depending on the type of enterprise. Small and medium-sized enterprises (SMEs) predominantly grapple with challenges related to skill acquisition, while micro-enterprises across Europe cite a shortage of funds as their primary impediment to innovation. Both categories of enterprises face a combination of traditional and emerging barriers that hinder their innovation efforts. In contrast, newly established firms, including startups and gazelles, do not view the emerging trends as significant barriers to innovation. This is likely because they frequently operate within these emerging areas themselves.

Insights on to what extent this reflects to the SMEs within mobility ecosystem are scarce. The SMEs 2021/2022 report gives only initial insights on the current state-of-play due to limited number of responses received. For the mobility ecosystem the highest challenges identified are cost pressures followed by disruptions in supply chains (Table 1). The sensitivity to the later is confirmed by the impact of the COVID-19 crisis having that mobility ecosystem is among only four that experienced decline in added value in the period 2019 to 2021. The challenges associated with skill supply should not be neglected. According to the same source, this issue, along with cost pressures, is expected to be more challenging for SMEs in the coming period.

Table 1: Importance of various challenges and issues faced by SMEs, the second half of 2021 [5, p.70]

	Finding customers	Finding staff	Cost pressures	Shortages of goods and materials due to supply chain disruptions	Access to finance
Aerospace and Defence	3.67	3.00	4.00	3.67	3.33
Agri-food	3.33	3.83	4.44	4.14	4.14
Construction	2.80	4.33	4.20	4.73	3.67
Cultural and Creative Industries	3.43	2.88	3.17	2.29	3.71
Digital	2.86	3.63	3.75	3.33	2.86
Electronics	3.00	3.50	3.71	4.38	3.50
Energy-intensive Industries	3.20	3.33	4.67	3.50	3.83
Energy - Renewables	2.80	3.67	4.00	4.00	3.17
Health	2.57	4.25	3.50	3.57	3.00
Mobility - Transport - Automotive	3.00	3.75	4.43	3.89	3.71
Proximity, Social Economy and Civil Security	2.40	3.33	3.40	2.00	3.83
Retail	3.13	3.38	4.00	3.17	3.80
Textiles	3.29	3.63	4.14	3.63	4.14
Tourism	2.56	4.00	3.76	2.33	4.31

Note: Respondents were asked the following question: 'Looking ahead to 2022, please rate the importance of each issue for SMEs in the 14 Industrial Ecosystems. Please rate on a scale of 1 (not an issue) to 5 (an extremely important issue)'.
Source: LE Europe survey of SME associations in Member States. 15 responses were received

2.2. Deeper understanding: survey results

Unlocking innovation potentials of SMEs requires deeper understanding of their needs. During 2023 in the framework of the project Horizon Europe INNO-MOB a survey on innovation needs of SMEs was conducted. It included 367 SMEs operation in Austria, Greece, France, UK, Bulgaria, Romania and Serbia. The survey also included Individual In-depth Interviews with 93 representatives of innovation support organizations. Most of the sampled companies were micro (43%), and small (31%). A dedicated questionnaire was used to discover challenges faced and innovation needs. The key results are as follows.

The primary challenges that companies are prioritizing involve trends associated with technological shifts, competitive pressures, as well as cost management and sales performance, which encompass delivering value to clients and generating revenue. This answers had the highest frequency of occurrence among offered answers. The lowest frequency of occurrence was recorded for legislation on production permits and cyber security. Less than one third of companies is facing problems with staff in terms of recruiting and training, while finding external partners stands out as a challenge especially in terms of technological challenges (60% of surveyed companies pointed to this challenge). While finding new clients is challenging for more than a half of surveyed SMEs both on national and international markets, it is a less issue when it comes to new products (for 30%). Financing innovations is a problem for nearly a half of respondents with the slightly higher percentage in the domain of investment in modernisation/new production facilities/ equipment (50%) than by R&D+I strategy/plan (incl. new product development) (46%) and investment in digitalisation (45%). Access to external funding sources stands out as a challenge with 78% of SMEs pointing to this problem,

While the findings mentioned above largely align with the challenges highlighted in official reports from the European Commission, one noteworthy observation deserving attention is that the substantial majority of the surveyed SMEs have not yet utilized the services provided by support networks. Additionally, an interesting discovery is that among the minority who did avail themselves of these services, satisfaction levels appear to be inversely related to the frequency of usage.

3 INNOVATION SUPPORT: STATE OF PLAY AND PROSPECTS FOR MOBILITY SMEs

3.1. General overview

Besides general programs targeting all SMEs independent of the sector/industry of operation, like INNO-SUP mentioned above, there are also sector/industry specific initiatives that aim to help SMEs to innovate, where industry clusters and networks play a pivotal role. Although innovation clusters and networks are drawing attention of both academics and practitioners in recent years, there is still lack of evidence on their key characteristics, nature and intensity of the actors' interaction [8].

3.2. The role of mobility clusters and networks

In the conceptual setting clusters are understood as regional concentrations of economic activities in related industries connected through local linkages but also interregional and global values chains that serve as competitive feature of the market economy [10]. On the other side networks of companies can act within or outside the cluster, and thus can be understood both as narrower or a broader concept. Both networks and clusters serve for building distinct capabilities and strategic positions, national and international linkages that are critical to access other markets, suppliers, and collaboration partner.

It is worth noting that there is still a lack of conceptual clarity as to what constitutes a cluster [11]. Based on thorough exploration John and Pouder [11] distinct between two generic types of clusters: technology-based and industry-focused. Industry-based clusters link the prosperities of the region to the economic cycle of one industry and are similar to a single business or vertically integrated business where all assets concentrated on the demand are provided by one industry. An example is Detroit, MI, auto cluster. On the other hand, technology-based clusters focus on early stage technologies and emerging markets, and can be seen as like a firm that participates in related diversified businesses. Typical example is Silicon Valley. Regardless of the type cluster organizations act as specialised SME intermediaries. They manage the collaboration, networking and learning in and provide or channel tailored business support service to group of specialised SMEs in the priority area [12].

When it comes to mobility sector the diversity of emerging technologies blur distinction between types of clusters. Specialised mobility technology clusters have automotive as the core category and are as expected located in areas automotive sector has traditionally thrived - Germany, France and the UK followed by cross-sectoral networks in Spain, Poland and Central Europe, Northern Italy and Sweden. [12] However, for the next decade, revenues and profits from manufacturing and selling motors and vehicles are forecast to be stable or even decline, while those from mobility services are expected to ascend [12]. Emerging mobility technologies are associated with the concept of smart mobility with increasing focus on energy efficiency, alternative fuels, shared mobility, automated vehicles and transport systems. This at the at same time creates challenges and opportunities for firms, depending on their ability and willingness to embrace change. As we discussed above (section 2.1) mobility SMEs are thriving in the aim to reduce emissions. On the other hand, larger players are already on a way to seize the opportunities. Automakers are shifting to new Business Strategies under the line "selling mobility instead of cars" and acting as the main operators of car-sharing services. [13] Examples are carsharing operators DriveNow owned by the automotive manufacturer BMW and Daimler AG's Car2go. In 2019 they merged and formed ShareNow which operated as one of the leading carsharing operators in Europe. In 2022 it ShareNow is acquisitioned by Free2Move subsidiary of the automobile manufacturer Stellantis. According to the report 'European panorama clusters and industrial change' [14] there are no regions where the SME effect is dominant. Large enterprises are leading in all other emerging industries as well but their effects is not so dominant as in the case of mobility (Table 2).

An example of merge between clusters is Eurocluster approved by the European Commission for the mobility, transport and automotive ecosystem in 2022. It includes five European clusters from France, Spain, the Czech Republic and Austria under the name RESIST: "REsilience through Sustainable processes and production for the European automotive InduSTry" and aims to act as One-stop-shop where SMEs from the mobility, transport and automotive ecosystem will be able to access to financing and implement projects that guarantee their sustainable growth.

Table 2 SME and large firm dominance effects for emerging industries [14, p.50]

	DOMINANT LARGE FIRM EFFECT (BETA SIZE > 0.55)	DOMINANT SME EFFECT (BETA PLANT > 0.55)	BOTH LARGE FIRM AND SME EFFECT POSITIVE
Advanced Packaging	64	5	17
Biopharmaceuticals	25	2	11
Blue Growth Industries	34	9	10
Creative Industries	14	2	10
Digital Industries	27	1	6
Environmental Industries	50	0	8
Experience Industries	28	6	15
Logistical Services	60	6	32
Medical Devices	41	3	6
Mobility Technologies	68	0	0

Like in the case of clusters this pan European cluster is also focused on automotive industry. At the same time priority sector report on mobility technologies point to mobility services as trend. According to the McKinsley insights [2, 15] demand services are coming along with electric vehicles and C-ITS systems while the most effective way to support SMEs is by pairing financial support with advisory services. This includes specific programs that typically operate to identify SMEs with high growth potential and provide them with the one-on-one support they need to realize this potential over a defined period of time. Support usually entails building capabilities, providing advice from experts, guiding transformation efforts, and arranging introductions and networking opportunities.
To summarize the dynamics of mobility innovations calls for synergies among established clusters and networks bit broadening the perspective of innovation support to innovation support providers more oriented towards business synergies and horizontal priorities like digital transformation.

4 MOBILITY INNOVATION NETWORK AS A BRIDGE BETWEEN SME NEEDS AND INNOVATION PROVIDER OFFERINGS

Making SMEs driving force in mobility innovations calls for collaboration outside the well-known and established clusters. Particularly around the cross-sectoral, horizontal development priorities where digitalisation stands out as an exemplar. Operationally this means spanning supporting networks outside the traditional offer and grasping a plethora of innovation support opportunities. This in turn also calls for adaptation and improvements of Innovation Support Organizations (ISpO) offer. In the following sections, an approach to achieve these objectives is outlined. It begins by illustrating the gap between the needs of mobility SMEs and the offerings of the ISpOs, and then proceeds to outline the foundational principles of the Pan-European Mobility Innovation Network

4.1. The Gap

According to the Gap Analysis from the INNO-MOB survey, besides rather traditional areas like ‘access to finance’ and ‘support in marketing and promotion’ two more fields where the gap between SMEs needs and ISpO offer is detected is related to energy efficiency and digitalisation support. These areas of mismatch (gap) are characterized by highest discrepancy between interest index (of SMEs) and ISpOs support availability index, along with highest discrepancy in ranking occurrence. For example, for energy efficiency support the difference between interest and availability index is 19%, while ranked on the fourth place by SMEs while in the same time it occupies 13th position in the ISpOs’ offer (Figure 2).

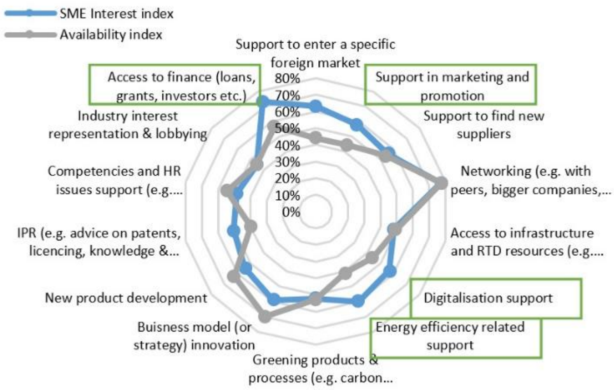

Figure 2 *Innovation services for mobility SMEs: Interest & Availability gap*

Source: Inno-Mob Survey
Note: SME interest index, calculated as a percentage of the number of answers: “I am interested in using such a service in next 12 months”, and half of the number of answers: “I would need more information to decide, if I am interested in using such a service in next 12 months” among the total number of respondents the SME survey. Availability index, calculated as a percentage of the number of declarations of the availability of the service category within the examined organisation’s portfolio among the number of respondents of IDIs.

Another point of interest is the quality of the services of ISpOs’ as perceived by SMEs. The results point to the tailored support and the time to delivery it. It is important noting that the ability to adapt to the needs of SMEs is not always the consequence of the absence of the will of ISpOs’ to do so but also come from legal constraints i.e. lack of ‘freedom to operate’. Namely, some BSO’s have predefined offer (like sectors of Chambers of commerce) and are not eligible or do not have capacities to offers support in specific areas like intellectual property rights (IPR).
Another significant finding pertains to the limited awareness among SMEs in the mobility sector regarding available innovation support. Additionally, Innovation Support Organizations (ISpOs) often lack the practice of gathering feedback from their clients to evaluate the outcomes and impact of the services provided, which could help enhance collaboration. Unlike sectors such as ICT and creative industries, mobility, particularly within the automotive sector, tends to adhere to a more traditional mindset and rigid value chains. SMEs, typically Tier 2 suppliers, encounter challenges in innovation compared to larger Tier 1 suppliers and OEMs.
In their pursuit of innovation support, SMEs in the mobility sector predominantly rely on traditional partners such as thematic clusters, networks, and conventional Business Support Organizations (BSOs) like chambers of commerce. Newer options in the landscape of innovation support organizations, such as accelerators, incubators, research and technology transfer offices, innovation hubs, and labs, are often perceived as supporters primarily for startups, despite their offerings being applicable to all companies with dedicated R&D departments. While incubators and

accelerators are often associated with startups due to their emphasis on early-stage growth, they are flexible and can be beneficial to a wide range of businesses and individuals at various stages of development, including scale-ups, established companies seeking innovation, researchers, and entrepreneurs in specific industries. Business accelerators are gaining prominence as significant components of business ecosystem development, although their precise role remains less understood, particularly beyond the IT sector [16]. An example of accelerator program in the field of mobility is initiative by European Institute of Innovation and Technology (EIT): EITs urban mobility programme launched in seven areas: Integrated Mobility; Sustainable City Logistics; Future Mobility; Mobility and Energy and Smart Infrastructure. Another example is European Innovation Council (EIC) accelerator challenge focused both on start/ups and SMEs in diverse areas including those horizontally connected with mobility sector like energy efficiency.

A significant discovery pertinent to the establishment of a pan-European innovation mobility network (the focus of this paper) arises from the distinctive attributes of the sample concerning economic activity classifications. Notably, 19% of the surveyed SMEs do not fall within the conventional sectors of activity, such as transportation services for goods or people, OEM (Original Equipment Manufacturer), Tier 1, or Tier 2 manufacturing. Within this proportion of SMEs dominant answers on sector of activity are related to mobility software solutions and applications, IoT and ITS solutions and shared mobility and MaaS operators. As highlighted in [17] as well as in the report from the ongoing project PANACEA[18] shared mobility service providers often operate outside the traditional standard classification systems and are mostly found within Technology sector, industry Software-Application. This adds to general findings (from McKinlsey reports) pointing to mobility service as an emerging market. Additionally, it poses difficulties in the recruitment of MIN members as traditional databases may fail to include important innovative market players.

4.2. The bridge

The specific innovation challenges encountered by Small and Medium-sized Enterprises (SMEs), as well as the identified limitations in the flexibility of Innovation Support Organizations (ISpOs), as discussed in preceding sections, highlight the imperative to establish a dedicated pan-European Mobility Innovation Network. This network would serve as a means to assist SMEs in overcoming innovation barriers and fostering proactive engagement. The foundational principles for its creation can be examined from both conceptual and operational perspectives. Conceptually, several building blocks emerge from research findings:

- Expanding beyond the scope of traditional support services.
- Establishing a continuous loop of improvement.
- Extending beyond the confines of automotive industry-related clusters and networks.
- Recognizing horizontal areas of interest.

As exposed in [18] Collaboration Platform emerges as a cornerstone in achieving this objective. Labelled as the Stakeholder Chain Map Intelligent Platform (SCMIP), it functions as the operational foundation for deploying the CIDDSM. The platform will facilitate mobility innovation networks, with a focus on the leveraging the inclusiveness of SMEs. The platform will bring together regional and national strategies and clusters, creating Pan-European clusters of diverse regions where stakeholders can identify opportunities for collaboration. Figure 3 illustrates the fundamental framework for MIN (Pan-European Innovation Mobility Network) development.

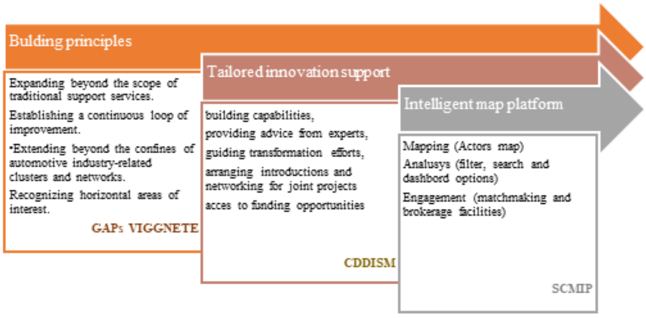

Figure 3 *Conceptual design of Mobility Innovation Network*

It begins with establishing principles outlined in this paper and well-recognized categories of support services. All of this will serve as the foundation for creating a customized service aligned with CIDDSM (Comprehensive Innovation-Driven Digital Service Model) and subsequently delivered through MIN, operationalized with the support of the SCMIP (Supply Chain and Mobility Innovation Platform). In essence, the MIN construction process will adhere to three core principles in stakeholder management: Mapping, Analysis, and Engagement, each of which is enriched by inputs from the conceptual phase of development.

5 CONCLUDING REMARKS

Unlocking the innovation potential of Small and Medium-sized Enterprises (SMEs) in the mobility sector necessitates a strategic approach that involves the revitalization of existing clusters and networks, their expansion to include a more diverse range of participants, and the pursuit of scaled-up engagement. This calls for the establishment of interconnected innovation network within the mobility domain, thereby bridging the existing gap between the innovation needs of SMEs and the offerings of Innovation Support Organizations (ISpOs). Drawing upon insights derived from official reports by the European Commission (EC) and key findings obtained through a recent survey involving 367 European SMEs operating in the mobility and transport sector, along with input from 93 innovation service support organizations, this paper articulated the foundational principles for the establishment of a pan-European innovation mobility network. The key point is that in light of the evolving landscape where mobility-related themes and technologies transcend the conventional boundaries of established industry sectors, such as automotive and transport, the imperative emerges for an interconnected innovation network that can adapt to these shifts. This network need be composed to incorporate a diverse array of innovation actors, particularly those engaged in cross-cutting areas associated with digitalization and energy efficiency.

The success of such a network hinges on the active participation and engagement of SMEs and innovation organizations. It underscores the critical notion that the design of network services is equally vital as the strategies employed for their promotion, the challenges anticipated, and the overall implementation plan. In essence, the effective design, promotion, and operation of these services are intrinsically linked to the network's potential for success.

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BLINDASSIST INFORMATION SERVICE FOR VISUALLY IMPAIRED PERSONS IN THE TRAFFIC ENVIRONMENT

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Abstract

The development of information and communication technologies and services plays a key role in improving the safety and mobility of people with disabilities when moving through the transport network. This paper analyses current information solutions available to visually impaired persons who navigate traffic networks using a white cane. Our objective was to evaluate the advantages and disadvantages of existing systems. By incorporating sensors and equipment, the white cane can be transformed into a powerful tool that enhances the user's overall accessibility and situational awareness. A proposal for BlindAssist, a service that provides visually impaired people with information on traffic network movement, is presented based on modern ICT. Testing and verification of the BlindAssist service effectiveness was done in laboratory conditions.

***Keywords**: Smart Wristband, Assistive Technology, Mobility, Smart Cities*

1 INTRODUCTION

According to the latest available data from the World Health Organization (WHO), there are currently 2.2 billion visually impaired people (blindness and low vision) in the world [1]. Visually impaired people (users) navigate the traffic network every day using a basic aid in the form of a white cane. The white cane as an aid helps the user to orient himself more easily in the space in which he moves (open and closed). The user goes through the methods of using the white cane through orientation and movement training. In doing so, he gets all the knowledge of where he is and how to use the aid. With such an approach, the goal is to increase the mobility of users moving through the traffic network.

Today's development of modern information and communication systems for informing users is the basis for innovative services development whose functionalities can increase the degree of user's mobility and make movement safer. Based on the analysed research in this area, certain shortcomings were recognized and listed.

The BlindAssist service aims to provide visually impaired individuals with accurate information to navigate through the traffic network effortlessly. The user equipment comes in the form of a smart bracelet, which is easy to use and allows users to customize the information they receive. The service offers various functionalities such as safe guidance, which informs the user about the safe movement zone and any potential obstacles in their path (in front of them and in the head zone), locating the user, establishing an SOS call and a regular call, receiving SMS messages, fall detection, and heart rate measurement.

2 PREVIOUS RESEARCH

Research in the field of development of new services with the aim of easier overcoming of everyday challenges when moving is based on the possibilities of certain communication technologies. With the development of intelligent transport systems (ITS) and associated services, the environment of traffic intersections can increase the level (feeling) of safety for users. A research paper [2] proposes the use of signal trilateration techniques and deep learning for image processing to segregate visually impaired pedestrians from others.

This segmentation can help in adapting the infrastructure and making it more user-friendly for all the stakeholders at the traffic intersection. The development of smart cities is centred around having a strong ICT infrastructure. This lays a good foundation for creating new services that inform users who navigate the traffic network of a smart city [3]. This, in turn, leads to an increase in the number of wearable devices such as smartphones, smart bracelets, and more. Services based on the Internet of Things (IoT) and Artificial Intelligence (AI) can be developed to improve the Quality of Life of users (QoL). The authors in the research [4] highlight the move towards the development of solutions for indoor and outdoor navigation of blind people using smartphones that offer cheap and simple options for the user.

The white cane is a fundamental tool that represents opportunity, freedom, and safety for visually impaired individuals. Recent studies explore the potential benefits of enhancing the white cane with advanced communication technologies [5]. These studies present the features of the equipment added to the white cane. Users can navigate through pedestrian paths and traffic intersections with the help of the white cane. Through orientation and movement training, users can learn about different movement techniques and recognize elements in the traffic intersection environment, such as tactile guidelines, tactile warning fields, descending curbstones. Research [6] provides an overview of smart cane technology and discusses challenges and research topics related to object detection and sensor feedback systems. A smart white cane in research [7] uses ultrasonic sensors and IoT connectivity to provide obstacle detection, GPS tracking, and communication features. The system uses a GPS module to send periodic emails with the location of the rod holder. One of the disadvantages is that the system works solely with Wi-Fi technology, the availability of which is limited or completely restricted in some locations. The main advantage of the solution is the combination of sound effects and vibration to provide warnings to the user and the ability to indicate obstacles from different directions. The InWalker system [8] improves the functionality of the white cane through the possibilities provided by IoT, GPS tracking, and SMS services. The system includes a panic button for emergencies and can detect ambient light which are the main advantages. The biggest drawback of the system is the precision of the sensors used, whose accuracy may be subject to the influence of environmental factors (objects from the environment and weather conditions).

Detecting pedestrian lanes is crucial for the functioning of autonomous navigation systems and user assistance systems [9]. Thanks to technological advancements, it is now possible to utilize deep learning methods to detect pedestrian lanes, road boundaries, and other environmental elements [10]. The main advantage of this system is pedestrian area detection in real time to help visually impaired people navigate and avoid obstacles. However, the system faces challenges in accurately detecting lanes in complex conditions and adapting the model to new environments with limited training data. In a study [11], AI and image recognition technology were utilized to detect and identify obstacles. However, the system's accuracy was found to be inferior to that of human recognition, which poses a significant threat to user safety. Another research [12] employed image processing to detect obstacles and basic geometry to calculate the distance between the device and the object. The system is very sensitive to angle changes, which greatly change the calculated distance. During walking, if the laser point is directed at such an angle that the laser point goes out of the image frame, it is impossible to detect the object.

In current research, the importance of using a basic aid has been observed, and a large number of authors are investigating the possibilities of pedestrian lane detection with modern technologies and methods. Numerous solutions use the help of electronic aids, such as those that use innovative technologies implemented in a white stick, all the way to navigation systems in mobile devices. The disadvantage of such solutions is large errors in obtaining accurate information, which can endanger a blind person's life. From the review of the currently available literature, the lack of the possibility of creating user profiles through web or mobile interfaces is visible, which makes it difficult to understand user requirements when using a certain information and communication system or service. In addition, most of the research relies on the use of smart mobile devices that users must carry with them to enable the functionality of the proposed system, but such presence of devices can result in disturbing the concentration of pedestrians in traffic areas when moving.

3 ORIENTATION AND MOVEMENT TRAINING METHODS

The concept of orientation implies the process of using sensor data to determine the position in space and the relationship of a person to objects in the surroundings important for orientation. Orientation is the knowledge of where a person is and requires the ability to observe and remember places and objects important for navigating a certain situation and the ability to determine the spatial relationships between them [13, 14].

With orientation, four important user orientation situations are distinguished:

- standing towards fixed points;
- moving towards fixed points;
- rest towards moving points and
- driving towards moving points.

The term movement refers to the ability of a blind or partially sighted person to move successfully, i.e., to independently overcome the distance from the starting point to the destination. A blind or visually impaired person can use the following methods in their movement within the traffic network:

- movement with the help of a white cane (the most common aid);
- moving with the help of a guide dog;
- movement with the help of a sighted guide and
- movement with the help of electronic aids.

All the methods mentioned above have specific forms of education for their application in particular situations such as navigating through the traffic network. Using a sighted guide requires education not only for the guide but also for the user. A white cane, which acts as an extended arm for blind people, allows them to sense obstacles physically. However, it is important to note that using a cane has a disadvantage, which is the lack of protection for the user's upper body (head).

Orientation and movement training can enable blind or partially sighted individuals to move independently. The training involves learning various techniques, including the following:

- Movement with the aid of a sighted guide - the visually impaired person holds onto the elbow of a sighted person who walks half a step ahead of them. With ample practice, this method is both practical and safe.
- Movement with the aid of a long white cane - the cane serves as the foundation for independent movement, and mastering this technique is essential for safety.

There are different techniques and tools used by visually impaired individuals to move around in different spaces. The sliding and touching technique are commonly used with a white cane in both open and closed spaces. Another technique involves following a wall using protective techniques to move in a closed space without a white cane or the help of a guide. Additionally, some visually impaired individuals use guide dogs to assist with their movement. There are also electronic aids that collect data about obstacles beyond the reach of the cane, but these can only be used as an aid with a white cane.

The success of a person's training can be determined by numerous factors, such as the skills and abilities acquired during the training, the perception of space, the feeling of safety while moving, and the knowledge acquired. It is best to conduct training in a real environment with everything that surrounds the person. If the person needs to travel from home to work or school, the instructor should accompany them.

The dynamics of traffic and other characteristics of the environment change constantly, such as characteristic sounds, noise intensity, possible landmarks, city traffic schedules, parked cars, and intensity of pedestrian traffic [15].

4 FUNCTIONALITIES OF THE BLINDASSIST SERVICE

The BlindAssist service is designed to assist users who navigate the traffic network. Its goal is to enable users to move more safely within the boundaries marked by the tape, which define the pedestrian path and traffic intersection. To move independently through the traffic network, users are recommended to receive orientation and movement training. This training equips users with the knowledge and skills required to move safely and efficiently, including the use of basic aids like the white cane. The training focuses on helping users identify accessibility elements that guide and inform them towards their intended destination, making it the most crucial part of the entire process.

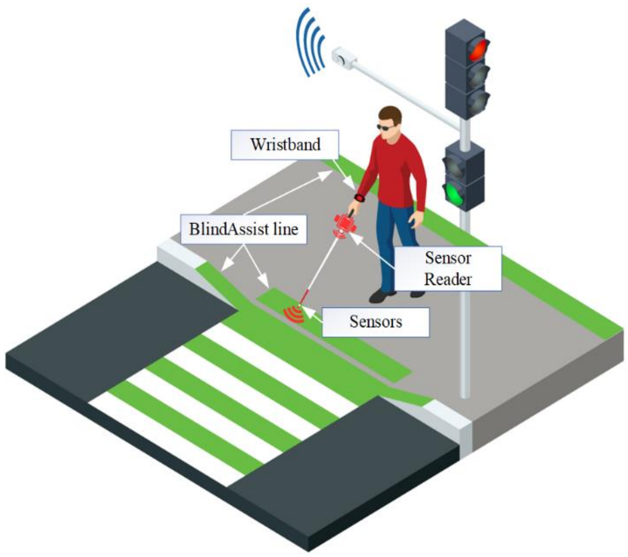

Fig. 1 *User movement through a pedestrian intersection using the BlindAssist service*

Figure 1 shows the concept of user movement through a pedestrian intersection using the BlindAssist service. The figure shows user equipment (white stick, smart wristband), BlindAssist line/warning field (accessibility elements), sensors and sensor reader. The smart wristband can deliver information to the user using vibration or TTS (Text to Speech) options. The BlindAssist service provides a visually impaired person with accurate information about moving through a safe zone and guidance to their destination. The sensor reader collects data on obstacles, objects, and the safe movement zone (BlindAssist lines).
Within the BlindAssist service, various functionalities are proposed, including routing, determining the precise location of the user, the ability to send and receive calls, and exchange SMS messages. In addition, as shown in Figure 2, it is possible to monitor the user's heart rate and detect possible falls. To guide the user, the service uses the ability to recognize safe zones for movement in the environment and the identification of objects in front of the body and the area above the user's head.

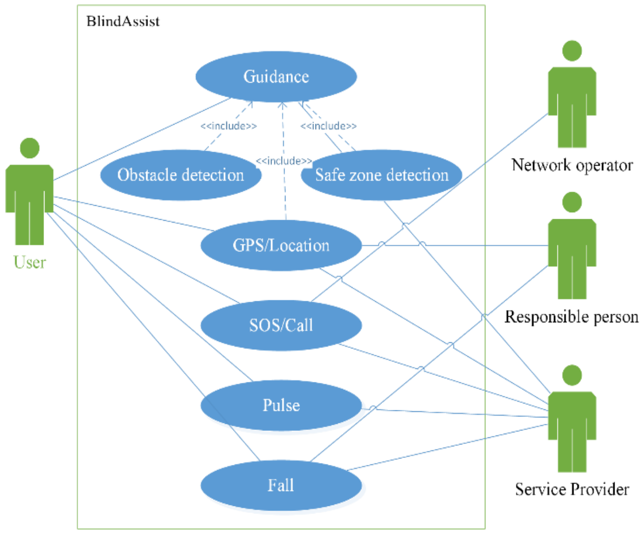

Fig. 2 *BlindAssist use case diagram presentation*

The BlindAssist service is connected to the mobile network by the network operator. This service enables users to make SOS or regular calls and allows them to send SMS messages. The responsible person has access to monitor the user's location. In the event of a user's fall or detection of an increased pulse level, it is possible to send an informative SMS message. The service provider facilitates all the functionalities mentioned above for the users.

5 CONCEPTUAL ARCHITECTURE OF THE BLINDASSIST SERVICE SYSTEM

5.1. Elements of conceptual architecture

To ensure the delivery of information to all participants of the BlindAssist service, a conceptual architecture of the system was developed. Figure 3 depicts the system elements necessary to deliver the service to the end user.
The user receives information through a smart wristband that uses a speaker and a vibration sensor. The wristband has pulse detection sensors, fall detection, and an eSIM module that helps establish an SOS call or regular call and communicate with the Cloud Computing (CC) system. When making an SOS or regular call, the user can use the microphone integrated into the wristband. The white cane is equipped with a sensor reader and appropriate sensors for detecting objects and following warning lines. The object sensor has the role of detecting obstacles that are in the path of movement in front of the user and in the area of the head, in which case the safety of the user's movement is important. Ultrasonic technology is used to detect objects.
The sensor for detecting lines and warning fields consists of a combination of several types of sensors [16]:

- Inspection sensor that belongs to the category of passive sensors and does not emit electromagnetic waves. To assess the orientation of the presence and accuracy of the surrounding objects, the inspection sensors use the images that are collected.

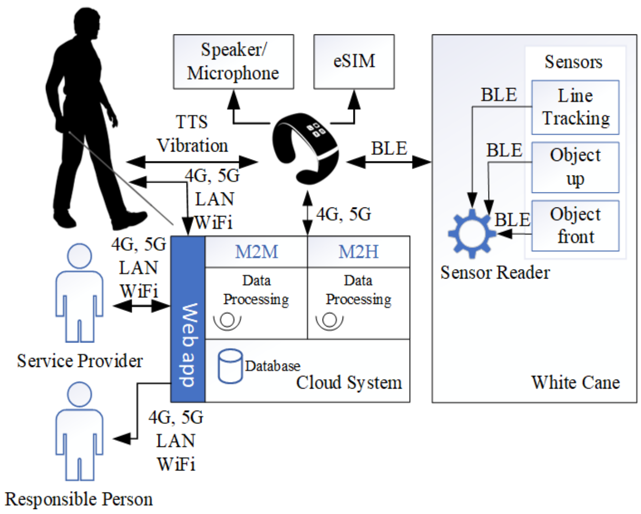

Fig. 3 *An overview of the elements of the system's conceptual architecture*

- The laser sensor is composed of a receiver and an installed transmitter, as well as the pulsed light of electromagnetic waves that are emitted through it. Also, the laser sensor uses infrared radiation with a wavelength of 800 to 950 [nm], and ultraviolet wavelengths of the electromagnetic spectrum above 1,500 [nm] are used.
- The radar sensor detects images of dust, snow, rain, and fog. Through the radar detection and ranging processes, a radar sensor emits powerful radio waves through a transmitter and receives them back through a receiver. Distances between sensors and objects are calculated according to the flight of radio waves.

system. Based on the entered data, the responsible person receives a link to accept the supervision role. During this time, they can track the user's location and verify their contact details.

The wristband and white cane communicate with each other via BLE (Bluetooth Low Energy) technology, which is suitable for efficient data processing and delivery of final information due to its technical characteristics such as low energy consumption, good coverage of 70 meters, easy connection and implementation of IoT services, and the ability to connect multiple devices using Bluetooth Mesh technology [17].

5.2. Ability to operate the BlindAssist service

Figure 4 demonstrates how the BlindAssist service operates through a sequential UML diagram. The user initiates the service on their smart wristband, which activates the sensors and readers. The line tracking sensor measures values that are cross-checked with the database located in the CC system. Feedback is then provided to the user in the form of TTS or vibrations, informing them about their movement within the safe zone or notifying them of the possibility of leaving the movement zone.

In addition, the object detection sensor, located in front of the user's direction of movement, uses an ultrasonic sensor to record the data that is then sent to the user, providing them with the calculated distance. Similarly, the sensor detects objects within the area and above the user's head. Moreover, the accelerometer, integrated into the wristband, is used to detect a fall. If a value of approximately zero [m/s^2] is measured, an informative SMS is sent to the responsible person, while the user is also notified in a defined form.

The pulse sensor records heart rate measurements and stores them in the user database. The CC checks for any

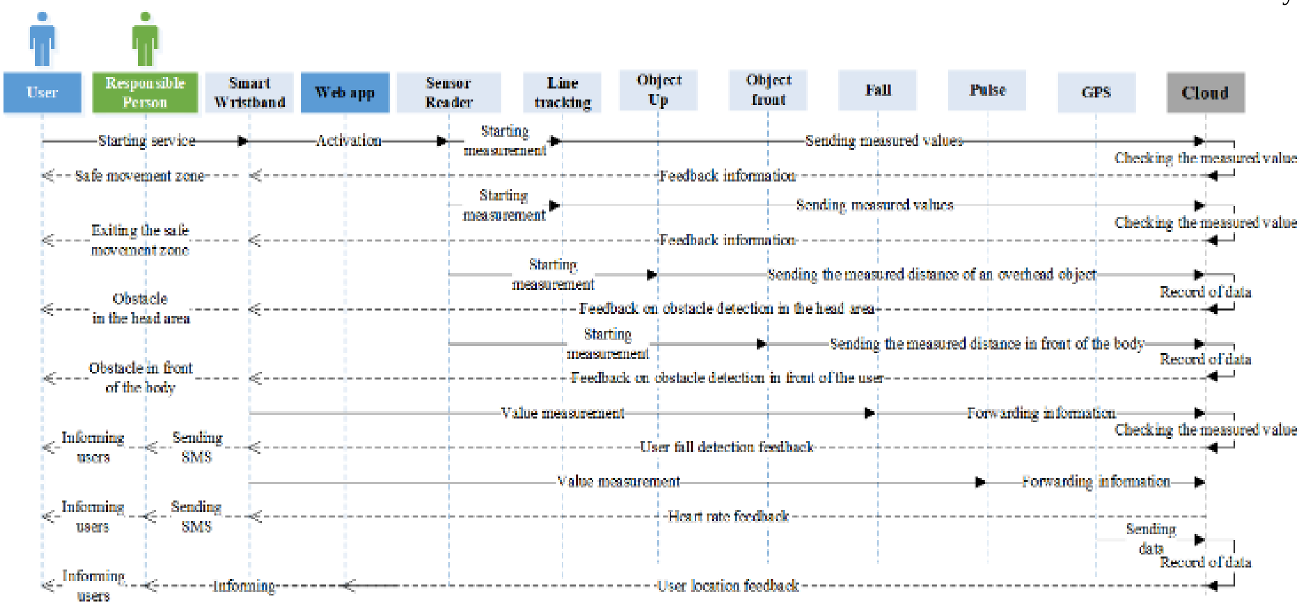

Fig. 4 *Presentation of the operation of the BlindAssist service with a sequence diagram*

The Cloud system serves as a repository for the system database that stores both user and sensor data. The user can enter their information through the web application, such as the type of damage, preferred information method, and contact details for the responsible person, along with the pulse reference value to register in the BlindAssist service

elevated levels, and if detected, sends an SMS to the responsible person while the user is notified through their smart wristband.

Additionally, the GPS coordinates are also recorded in the database and can be accessed by both the responsible person and the user.

6 BLINDASSIST SERVICE PERFORMANCE TESTING

Performance testing of individual elements of the Blind Assist service was done in laboratory conditions (Laboratory of Development and Research of Information and Communication Assistive Technology, Department of Information and Communication Traffic). The goal of the test is to check the effectiveness of reading data from the environment of the user moving through the traffic network and their storage in the CC environment. The sensors and components used for testing are shown in Table 1.

Table 1 Sensors and components used for testing

Sensor and components	**Functionality**
Arduino Mega 2560	Microcontroller
Arduino Ethernet Shield	LAN communication
Velleman TCRT5000	Line tracking and detection sensor
Ultrasonic Sensor HC-SR04	Obstacle detection sensor
PIR motion	Sensor for detection of objects from the environment
Accelerometer	Fall detection
GPS	User location

The sensors and components listed in Table 1 are connected according to the conceptual architecture, where the white stick is equipped with obstacle detection sensors (above the head and in front of the body) and a line tracking sensor. To simulate the environment in CC, the ThingSpeak environment was used. Figure 5 shows data obtained from sensors for detecting lines and objects in the environment. The left side of Figure 5 shows the value 1 when the sensor detects the marked line and the value 0 when the user moves within the safe zone.

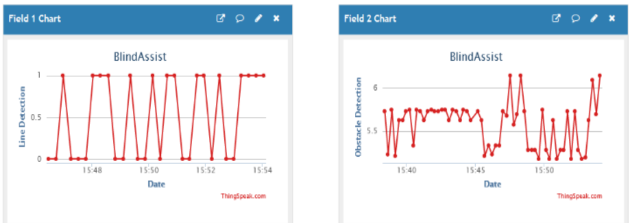

***Fig. 5** Collection of line and object detection data*

The right side of Figure 5 represents object detection on the measured values expressed in centimetres (interval from 5.17 [cm] to 6.13 [cm]).

When detecting objects or landmarks, the sensor prints the message "Object detection". After moving the user away from the sensor coverage area, the user is informed with the message "Object detection ended". The left side of Figure 6 illustrates the object detection sensor located in front of the user at a distance of 1 [m], while the right side shows the measured values of the accelerometer, precisely marking the zero velocity [m/s^2], indicating the detection of the user's fall. The obstacle detection sensor measures the distance between the user and the obstacle and uses the intensity of the vibration to notify the user of approaching obstacles.

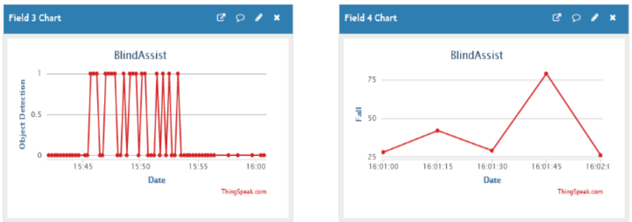

***Fig. 6** Collection of detection data from the user's environment and possible fall*

As per the proposed architecture, the GPS sensor and accelerometer for tracking the user's location were integrated into the smart wristband. The Android MIT App Inventor platform was used to test the application environment. Figure 7 displays the relevant program code section for measuring the user's acceleration via the smart wristband.

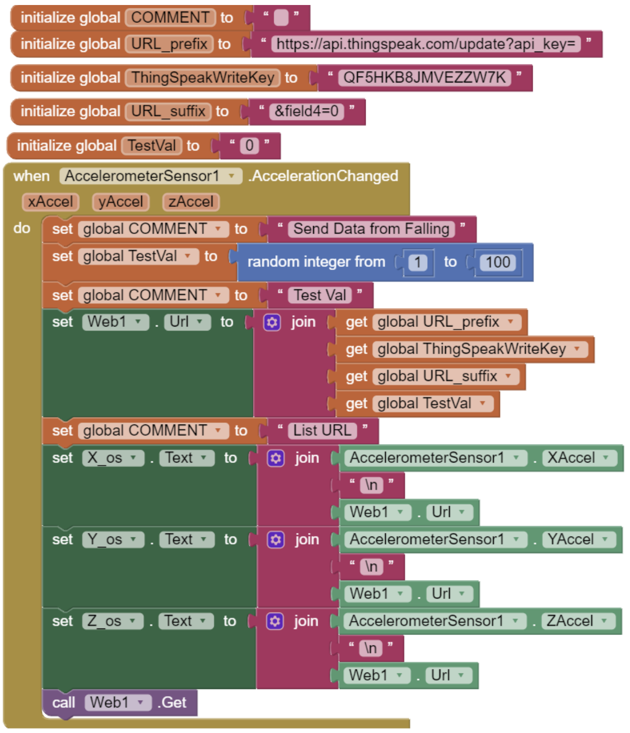

***Fig. 7** MIT App environment for user fall detection*

Figure 8 illustrates all the tested components that are integrated into the white cane. Functionality tests is conducted in a controlled indoor environment to evaluate the movement and detection of marked lines and objects. The controlled environment ensured that the ultrasonic sensor was not affected by any negative influences.

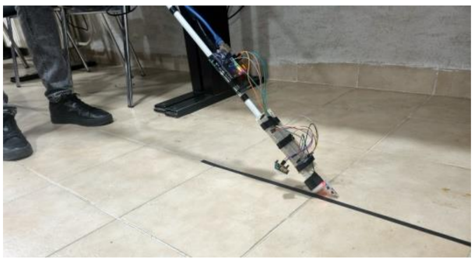

***Fig. 8** BlindAssist service components*

7 CONCLUSION

People with visual impairments face difficulties and challenges in their daily activities, particularly when navigating the traffic network. Navigation of visually impaired people using modern information and communication systems and solutions has significantly improved their daily activities. Also, constant education and work with visually impaired people can ensure a greater degree of safety, independence, and user orientation when moving.

BlindAssist is a modern service integrated into the user's basic aid that seeks to increase mobility with minimal infrastructural interventions on the traffic infrastructure using the lane recognition system. This system brings together all the elements of accessibility used today when conducting orientation and movement training and is an essential part of the traffic network in cities and settlements. These elements include tactile guidelines, tactile fields, and warning lines.

In laboratory conditions, tests confirmed the sensors' ability to identify key elements and obstacles that are crucial for the safe movement of users. This approach opens up new possibilities for increasing mobility, considering that not all pedestrian routes in urban areas have tactile elements of accessibility.

The proposed service requires minimal technical requirements, primarily the marking of pedestrian routes with reflective lanes, which is already widespread in many cities today.

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Using Dynamic Programming to Reduce Traffic Congestion from Work Zones in Cities

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Abstract

Work zones can significantly increase traffic congestion on streets, roads, and in cities. Depending on the nature of construction and/or rehabilitation activities, the street capacity may be to a large extent decreased or the street may be totally closed. Work zones cause traffic delays on the street where maintenance is being performed, and they also increase traffic flow on nearby streets as drivers change their usual routes.There are numerous possible work zone schedules. The work zones scheduling problem belongs to the class of combinatorial optimization problems. The chosen work zone schedule has a large impact on the overall travel time of all network users. We considered the bi-level work zones scheduling problem. The upper level's objective function, to be minimized, represents the total travel time of all network users. Relations in the lower level, help us to compute User Equilibrium flows. Work zones scheduling problem could be solved in stages, where the stages are connected through recursive computation. The proposed approach to the problem is based on the combination of the Dynamic Programming technique and the heuristic traffic assignment method. The model developed is tested on numerical examples.

***Keywords**: Work Zones, Scheduling, Traffic Assignment, Dynamic Programming.*

1 INTRODUCTION

Over the past few decades, there has been a substantial rise in the volume of private car trips in cities and on highways. Unfortunately, the capacities of road networks have not kept up with this increase in travel demand. As a consequence, urban road networks in many countries have become highly congested, leading to longer travel times, frequent stops, unforeseen delays, higher travel costs, increased air pollution and noise levels, and an increased occurrence of traffic accidents.

The deteriorating condition of highways and street infrastructure in many cities has resulted in an increase in the number of construction and rehabilitation work zones. Work zones contribute significantly to traffic congestion in streets, roads, and cities [1-5]. Depending on the type of construction or rehabilitation activities taking place, the capacity of the street can be significantly reduced or the street may be completely closed. As a result, the work zone causes traffic delays on the affected street. Additionally, the work zone leads to increased traffic on neighboring streets as many drivers alter their usual routes. When a specific schedule is implemented, network users quickly become familiar with the new network topology resulting from the specific work zone activity. They seek out the most convenient routes through the network, creating again user equilibrium conditions in a network. Put simply, each work zone schedule generates a new network topology and corresponding traffic conditions where user equilibrium is achieved. Obviously, the overall travel time of all network users is greatly influenced by the chosen work zone schedule.

There are multiple potential schedules for work zones. The problem of determining the optimal work zones schedule belongs to the class of combinatorial optimization problems.

The main objective of this paper is to explore the possibilities of using the exact algorithms to schedule planned maintenance activities in a manner that minimizes disruptions for network users. Specifically, we aim to identify the work zone schedule that minimizes the total travel time for all users due to the presence of work zones. We present the work zone scheduling problem as a bi-level program.

The rest of the paper is organized in the following way. The methodology is explained in Section 2. Section 3 contains the results and the discussion. Section 4 contains the conclusion and recommendations for future research.

2 METHODOLOGY

We solve the work zones scheduling problem by forward procedure of Dynamic Programming (DP) [6, 7]. In order to clarify computations, we form a network of the considered problem. In the first step of network construction, we define the stages. In our problem, each day of the observed time period represents one stage.

We add the initial stage (stage 0) for computational convenience. Since we add the initial stage, the total number of stages is one greater than the total number of days in the observed time period, where stage j refers to day j of the observed period.

The maintenance activities can start simultaneously, some, for example, may begin on the third day, others on the fifth day, etc., but all activities must be completed within the observed time period. Each state (x_j) in each stage j represents a possible combination of the cumulative duration of individual activities up to that point. For example, the combination (0, 2, 1, 4) on the fifth observed day indicates that no work has been done in the first street up to the fifth day, two days of work have been completed in the second street, and only one day of work has been done in the third street, and four days of work have been completed in the fourth street so far. The value of the objective function $f_j(x_j)$ represents the total travel time of all drivers from the first day to the j - th day in the case when the reconstructions were performed in the manner defined by the state of x_j. In order to calculate this total travel time, it is necessary to find the user equilibrium flows for each of the observed days and calculate the corresponding total travel time for that day.

Let us illustrate the proposed approach with a toy example. Let us assume that it is necessary to schedule two activities over a period of time that is three days. The duration of the first activity is two days, and the second activity one day. Figure 1 shows a graphic representation of the stages and states in this example. Each state is represented by one node in the network. For the sake of easier calculation, let us introduce the initial stage as $j = 0$. The other stages represent days. The first stage refers to the first day, the second to the second, and so on. From Figure 1, it can be seen that there are a total of 10 states. The description of individual states is given in Table 1. State 0 is the initial state in which neither activity 1 nor activity 2 has been implemented. In the first day (stage 1), there are 4 possible states. In state 1, neither activity 1 nor activity 2 has started yet. State 2 refers to the situation when the number of executed working days of the first activity is equal to 1, and the number of executed working days of the second activity equal to 0. State 3 describes the situation when the number of completed working days of the first activity is equal to zero, and the number of completed working days of the second activity equal to 1. The fourth state indicates the situation when the number of completed working days in both activities is equal to 1, etc. Each state, in addition to information on the number of working days of individual activities, is also characterized by the total travel time of all network users from the beginning of our observation. It is most often possible to reach every state from several different states in the previous stage. For example, state 6 can be reached from states 1 and 3 (Figure 1). When we calculate the total travel time of all users that is related to a certain state, we are actually calculating the length of the shortest path leading from the starting node to the node in the network that represents the observed state. When we find the shortest path leading from the starting node $j = 0$ to the final node in the last stage, we have found the starting times of each of the activities. For example, if the shortest path in the network in the picture would be state 0 - state 2 - state 7 - state 9, this would mean that on the first and second day only activity 1 is realized, and on the third day, work is performed only on activity 2.

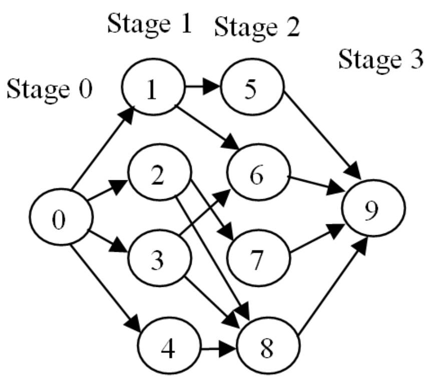

Fig. 1 Toy example

Table 1 States description

Stage	State	Activity 1 number of days of work executed	Activity 2 number of days of work executed
0	0	0	0
1	1	0	0
1	2	1	0
1	3	0	1
1	4	1	1
2	5	1	0
2	6	1	1
2	7	2	0
2	8	2	1
3	9	2	1

The Dynamic Programming forward recursive equation reads:

$$f_j(x_j) = \min_{\substack{for\ all\ feasible \\ links\ (x_{j-1}, x_j)}} \{f_{j-1}(x_{j-1}) + C(x_{j-1}, x_j)\} \quad (1)$$

and

$$f_0(x_0) = 0 \quad (2)$$

where:

j – stage
x_j – state at the stage j
$f_j(x_j)$– the objective function value at state x_j at stage j
$C(x_{j-1}, x_j)$ – the difference between the objective function values for state x_j and x_{j-1}.

The value of the objective function $f_j(x_j)$ represents the total travel time of all drivers from the first day to the j - th day in the case when the reconstructions were performed in the manner defined by the state of x_j. In order to calculate this total travel time, it is necessary to find the user equilibrium flows for each of the observed days and calculate the corresponding total travel time for that day.

We calculate user equilibrium flows by using the incremental assignment heuristic [8, 9]. The value $C(x_{j-1}, x_j)$ represents the total travel time of all users on the network on the j - th day, in the case when the order of execution of the planned activities is defined by states x_{j-1} and x_j.

Finding the value of the total travel time was performed for each possible schedule of the considered maintenance activities on the network.

This procedure was performed before dynamic programming began. A pseudo-code of the incremental heuristic algorithm reads [8, 9]:

Step 0: Split each origin-destination flow into I equal shares, i.e.:

$$q_{rs}^i = \frac{q_{rs}}{I} \quad (3)$$

Set iteration counter $i = 1$ and $x_a^0 = 0, \forall a$.
Step 1: Set $t_a^i = t_a(x_a^{i-1}), \forall a$.
Step 2: Make all-or-nothing assignment of shares q_{rs}^i, based on travel times $\{t_a^i\}$. Get a set of link flows $\{y_a^i\}$.
Step 3: Set $\{x_a^i = x_a^{i-1} + y_a^i\}, \forall a$.

Step 4: If $i = I$, finish the algorithm. Otherwise, set $i = i + 1$, and return to step 1.

3 RESULTS AND DISSCUSION

The proposed dynamic programming algorithm was tested on the Sioux Falls network. This network has 24 nodes and 76 links and is shown in Figure 2. This network is very often used as a benchmark example in many traffic engineering problems. Table 2 provides characteristics of the rehabilitation activities that need to be done. As can be seen from the table, two cases were taken for testing, which differ in the duration of the activities. In the first case, the activities end up shorter (duration times are given in the third column), and in the second longer (fourth column).

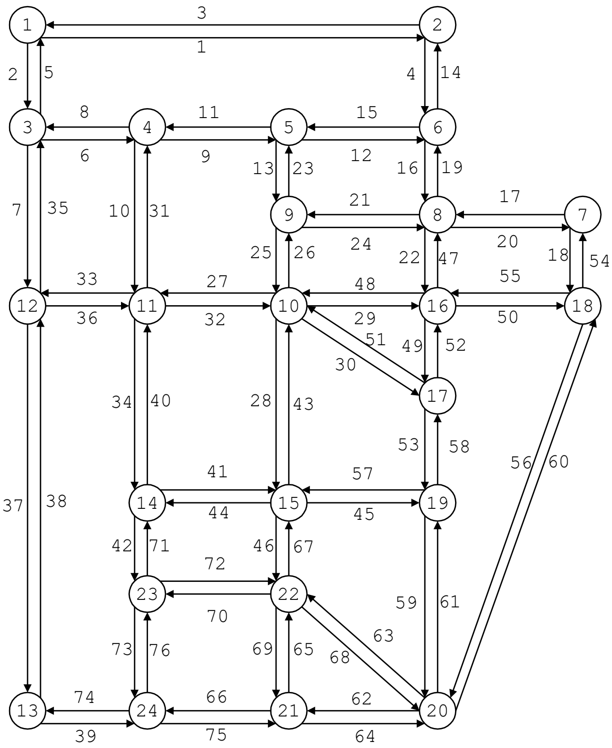

Fig. 2 Sioux Falls network

Table 2 Characteristics of the rehabilitation activities [10]

Activity	Link number	Case 1 Duration of shorter activities (days)	Case 2 Duration of longer activities (days)
1	25	2	8
2	24	3	5
3	42	4	7
4	27	2	4
5	8	4	8
6	10	1	9
7	66	2	10
8	44	3	12
9	45	2	8
10	56	3	10

To solve the integer programs, we have used the professional software CPLEX 20.1. Dynamic programming and incremental traffic assignment algorithms, we programmed in the Java programming language. All tests were performed on a laptop computer with the following characteristics: 11th Gen Intel(R) Core(TM) i7-11800H @ 2.30GHz, 16 GB of installed RAM, and Windows 11 operating system.

Tables 3 to 6 show the results obtained by solving integer programs, and using dynamic programming. Tables 3 and 4 show the results obtained for periods of 15 days, and Tables 5 and 6 show obtained results for 30 days period. For a simpler presentation, the values of the objective functions are expressed as the average travel time per vehicle (obtained by dividing the total travel time by the total number of trips (360600)). Given that both techniques provide optimal solutions, the values of the objective function are the same for both methods. Therefore, the value of the objective function for each instance is shown in only one place.

Based on the results shown in Table 3, for 15-day period and shorter activity durations, dynamic programming was more efficient in solving if the number of activities was from 1 to 6, and then CPLEX was significantly faster. It can also be seen that CPLEX was able to solve the instance with 10 reparation activities after 2832.2 seconds, while we stopped the execution of the program with dynamic programming after several hours, so we did not manage to reach a solution with it.

Table 3 Results obtained for the 15-day period and shorter duration of activities

Instance	Average travel time [min]	CPU time [s]	
		CPLEX	Dynamic Programming
1	26.16	0.06	0.0
2	27.28	0.16	0.017
3	30.59	0.02	0.017
4	31.74	0.56	0.06
5	33.08	2.61	0.347
6	33.27	6.08	0.964
7	33.67	6.00	17.398
8	34.70	11.64	400.482
9	35.39	111.61	2705.401
10	35.77	2832.20	-

Similar results were obtained in the case of 15-day period and longer duration of activities (Table 4). In these instances, dynamic programming was faster in solving instances 1 to 5. Instances 8, 9 and 10 were not solved by dynamic programming. Regardless of whether CPLEX succeeds in reaching a solution on this set of instances, it is clear that there is a significant increase in computing time as the number of tasks to be performed increases.

Table 4 Results obtained for the 15-day period and longer duration of activities

Instance	Average travel time [min]	CPU time [s]	
		CPLEX	Dynamic Programming
1	29.77	0.08	0.016
2	31.10	0.13	0.0
3	36.18	0.17	0.019
4	38.60	0.52	0.031
5	41.95	2.50	0.448
6	44.00	6.31	9.054

7	49.09	7.58	486.812
8	57.51	16.58	-
9	64.59	246.28	-
10	67.56	1756.78	-

We have presented the results obtained for the 30-day period in Tables 5 and 6. There is a great similarity in the observations as well as the results for the 15-day period. For activities of shorter duration (Table 5), it was found that dynamic programming solves faster instances when the number of activities is from 1 to 6. For more activities, CPLEX was more efficient. This observation is also confirmed in the example with longer activity duration (Table 6). In this case, dynamic programming solved instances with the number of activities from 1 to 4 faster, while CPLEX was more efficient with more activities. Based on the table, it can also be observed that neither CPLEX, nor dynamic programming, were able to solve instances 9 and 10, in the case of shorter activities, as well as examples from 6 to 10 activities, in the case of longer duration activities.

Table 5 Results obtained for the 30-day period and shorter duration of activities

Instance	Average travel time [min]	CPU time [s]	
		CPLEX	Dynamic Programming
1	25.56	0.09	0.017
2	26.12	0.09	0.013
3	27.77	0.44	0.031
4	28.35	3.86	0.096
5	29.02	15.80	0.643
6	29.11	75.59	2.463
7	29.31	13.95	47.345
8	29.83	584.86	1068.073
9	-	-	-
10	-	-	-

Table 6 Results obtained for the 30-day period and longer duration of activities

Instance	Average travel time [min]	CPU time [s]	
		CPLEX	Dynamic Programming
1	27.36	0.09	0.013
2	28.03	0.16	0.016
3	30.56	2.14	0.111
4	31.78	10.58	1.501
5	33.15	28.19	98.594
6	-	-	-
7	-	-	-
8	-	-	-
9	-	-	-
10	-	-	-

4 CONCLUTIONS

Work zones scheduling problem belongs to the class of combinatorial optimization problems. In this paper, the possibility of solving it by dynamic programming is discussed. The developed algorithm was tested on an example from the literature, and the results were compared with the results obtained by mixed integer programming technique using the CPLEX software. By comparing the obtained results, it was observed that the dynamic programming algorithm is more efficient in examples with fewer activities that need to be performed on the network. In examples with a larger number of activities, the CPLEX software was far more efficient. However, in the case of both solution approaches, it can be observed that their CPU times can significantly increase with the increase in the number of activities and the time period of observation. Based on the obtained results, it can be concluded that the presented exact algorithms for this problem can be used effectively only if a smaller number of activities is considered. For example, with more activities, it is obviously necessary to use heuristic algorithms. This is the main direction of future research.

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til 2023

FUTURE TRENDS IN THE DEVELOPMENT OF TRANSPORT AND MOBILITY TECHNOLOGY

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Abstract

Transport as a logistics subsystem is the main cause of costs, but also one of the major generators of changes in the economic state of a country. Transport technologies are constantly being improved with a focus on electrification, the concept of zero emissions of harmful gases, autonomy and the smart concept. In this paper, future trends in the development of transport and mobility technology are briefly discussed: Autonomous Aerial Vehicles (AAVs), Delivery Drones, Driverless Cars, Flying Hotels, Flying Taxis, Flying Bicycles, Hyperloop, Maglev Trains, Micromobility, Self-Driving Taxis, Smart Roads, Underground tunnels.

Keywords*: smart concept, autonomous vehicles, robots, mobility, transport*

1 INTRODUCTION

Transport is one of the first and widest fields of application of artificial intelligence. Considering the complexity of the transport industry and numerous areas that transport covers, it has always been one of the fields that first implemented the latest technologies and innovations, and so it is now, when it comes to artificial intelligence. Nowadays, the global world is experiencing rapid changes and long-term challenges, constant consumption of natural resources, uneven reduction and increase in population growth. The emphasis is on improving transport through achieving zero carbon emission, separating economic growth from the unlimited use of resources and energy, ensuring competitiveness and energy stability. Electric cars are the future of green mobility as even electric flying cars are being considered and produced. High fuel prices and bad climate led to an increase in consumer awareness, so the electric vehicle has found its place again aiming at further development and use. The impact of transport on the environment results in the pollution of land, air, water, and it also has a negative effect on the environment by creating noise and vibration. Hydrogen is an energy carrier that can be obtained from sources that contain very little carbon, an element that is produced by burning fossil fuels. In general, a hydrogen vehicle is more expensive than an electric vehicle due to the fuel cell system. The country that is becoming the leader in the race to develop electric vehicle technology is China, with a goal to reduce the negative impact of vehicles on the environment, and thus to increase its competitiveness in the sale of its electric vehicles.

2 INTELLIGENT TRANSPORT SYSTEMS

ITSs provide numerous benefits resulting from the enhancement of operational efficiency and reliability of the services offered, improvement of production in the management of transport infrastructure, as well as better safety, environmental impact reduction and various information services provided to users. ITS can be applied to any means of transport and can refer to: vehicle, infrastructure and user (driver or passenger).

***Figure 1**. ITS [20].*

2.1. Application of intelligent systems in transport

Transport is one of the first and widest fields of application of artificial intelligence. Considering the complexity of transport activities and numerous areas that transport covers, it has always been one of the fields that first implemented the latest technologies and innovations, and so it is now, when it comes to artificial intelligence.

2.2 Intelligent transport services

ITS systems ensure the collection of a large set of different data from intelligent equipment, business systems, the environment, social networks, etc. Intelligent equipment is installed in transport vehicles, transport infrastructure and monitoring and control systems. Business systems include government services, ministries, public enterprises, agencies, maintenance services, various enterprises and companies.

3 ELECTRIFICATION

In order to reduce greenhouse gas emissions into the atmosphere, efforts are being made to replace conventional fuels with production from renewable energy sources. The technologies that receive the most attention are related to the introduction of different types of electric vehicles in transport systems and the use of renewable energy sources in energy systems. Technological innovations in autonomous vehicles, cars, buses and delivery vehicles, can lead to less traffic congestion.

3.1 Electric car as a car of the future

Electric cars are the future of green mobility as even electric flying cars are being considered and produced. Today, the electric car has become very interesting again since modern sustainable development is based on ecology and energy saving.

3.2 Hybrid vehicles

Hybrid car drive is a name that means starting a car using several different sources of energy, primarily an electric motor (accumulator) and an internal combustion engine, and combines the advantages of both sources depending on the type of driving or operating mode. One of the most important differences between hybrid powered cars and electric cars is in their batteries and charging and discharging of accumulators.

Figure 2. *Hybrid vehicle [22]*

4 TENDENCY TOWARDS A CONCEPT OF ZERO EMISSION OF HARMFUL GASES

Unlike cars with internal combustion engine, electric cars are more environmentally friendly. When using electric vehicles, there are no emissions of harmful gases, thus a negative impact on the environment reduces. Since electric vehicles are emission-free, they also contribute to reducing the growth of greenhouse gases.

4.1. Hydrogen and fuel cell heavy goods vehicles

A hydrogen vehicle is less sensitive to the costs associated with increasing range because the range is only increased by a larger tank or tank pressure which is significantly cheaper than lithium-ion batteries per kWh. Predictions are that the ratio of electric vehicles to hydrogen vehicles will be in the ratio of 50:50, while biofuel vehicles will remain mostly in the USA.

4.2. Electric buses in China

Since it is predicted that electric vehicles will almost completely replace vehicles with internal combustion engine, more and more countries are aiming to introduce technology that will make this transition possible. The country that is becoming the leader in the race to develop electric vehicle technology is China, with a goal to reduce the negative impact of vehicles on the environment, and therefore to increase its competitiveness in the sale of its electric vehicles.

Figure 3. *Electric bus [24]*

5 AUTONOMOUS VEHICLE

An autonomous vehicle can be defined as a self-driving car under computer control, i.e. based on artificial intelligence. Such cars combine sensors and software to control and manage the vehicle. It is believed that smart cars will be exclusively battery-powered autonomous vehicles and that the number of traffic accidents will be significantly reduced.

Figure 4. *Autonomous vehicle [21]*

5.2. Autonomous truck

Autonomous trucking is a term used to describe self-driving tractor-trailers that transport goods. The goal of autonomous trucking is to have one day big platforms and delivery trucks, carrying the things from point A to point B without human intervention.

Figure 5. *Autonomous truck [16]*

Autonomous trucks operate by using sensor technologies such as LiDAR (sensor technology that uses light to determine distance), radar and optical cameras to collect visual data from the surrounding area.

5.3. Futuristic vehicle design

Design as the visual appearance of a vehicle, along with the desired appearance by designers, largely depends on aerodynamics. The main goals of designers are to reduce the noise caused by the wind hitting the body of the vehicle, and to increase the aerodynamics of the vehicle, so that the vehicle has as little resistance as possible when moving. An aerodynamic vehicle has a crucial impact on fuel consumption by reducing wind resistance on the exterior of the vehicle and reducing losses associated with airflow and engine cooling requirements [9].

***Figure 6**. Futuristic vehicle design [17]*

5.4. Flying cars

Current technological development indicates that flying cars may be available for commercial use by 2025 [1] and [2]. The evolution of flying cars will require new policies and standards to regulate the transition and handover periods between manual and autonomous vehicle control and the complex transition between ground and flight dynamics. Flying cars will be highly automated, computerized and likely connected to an encrypted network for navigation purposes. Such a system will prescribe policies to enable protection against cybercrime.

***Figure 7**. Flying car [15]*

5.5. Autonomous aircrafts

Control functions for unmanned aerial vehicles can be on-board or off-board (remote control). Vehicles that can be considered autonomous must be able to make decisions and react to events without direct human intervention. There are some fundamental aspects that are common to all autonomous vehicles. These aspects include the ability to sense and perceive the environment, analyse the information obtained, communicate, plan and make decisions, as well as act using control algorithms and actuators [8].

***Figure 8.** Autonomous aircrafts [18]*

6 FLYING HOTEL

Existing only in theory, flying hotels are aircrafts designed to stay in flight while accommodating passengers for longer stays. Guests check into their own designated pods, with access to common areas throughout the property. It is envisaged that the Sky Cruise would fly without a pilot, it would be completely autonomous, and under the supervision of an artificial intelligence system.

6.1. Sky Cruise Hotel

The Sky Cruise Hotel is a 5,000-passenger luxury concept hotel with restaurants and bars, a shopping mall, gyms, medical centres, cinemas, swimming pools, outdoor elevators, event spaces, and a 360-degree AI-driven observation deck designed to stay in the air, and only landing to pick up or drop off guests. The catering model, which would be powered by 20 nuclear fusion engines, is a theoretical facility envisioned by engineer Hashem Al-Ghaili. Supplies and guests are transported to the hotel by an electric commercial aircraft, and maintenance is performed above the ground.

***Figure 9**. Sky Cruise Hotel [19]*

6.2. Driftscape

The project qualified as a top three finalist for the Radical Innovation Awards, a competition for technological innovation in hospitality and travel. The idea, which comes from the Canadian design company HOK, is for each room to be a flying glass pod. The pods would be connected to the main stationary hub, but could be detached to allow guests to fly around at a specific location.

***Figure 10**. Driftscape [13]*

6.3. Flying taxi

One of the latest innovations in technology, eVTOL aircrafts are electric aircrafts that take off and land straight up and down. Short for electric Vertical Takeoff and

Landing aircrafts, eVTOLs are sometimes called air taxis or flying taxis. Powered by batteries, eVTOLs hover and fly, much like a helicopter, and are typically designed to carry two to six passengers, including a pilot.

Figure 11. *Flying taxi* [30]

6.4. Flying bicycle

Hoverbikes or hovercycles are bicycles that fly. The hoverbike is classified as a type of mobile personal transport similar to a skateboard, but uses magnetic means of levitation instead of wheels. This new product has so many additional features, such as solar shade with USB port and compression seat, which will make users' daily life routine easier. [7].

Figure 12. *Hoverbike [31]*

7 DELIVERY DRONES

Aerial vehicles without pilots (also known as unmanned aerial vehicles - UAVs, or remotely piloted aerial systems) are a relatively new mode of transport that is undergoing significant investment and development to support their use as delivery vehicles [5]. Despite the growing interest in the use of drones for logistics, particularly in the medical sector, there is little understanding of what the risk of drone delivery is compared to traditional logistics methods or other land transport types. Delivery drones are unmanned aerial vehicles designed to distribute light packages as part of the last mile delivery process. It is estimated that autonomous vehicles would deliver 78% of items globally in the future, while traditional delivery will participate with around 20% [6].

7.1. Amazon Prime Air and Project Wing

Amazon Prime Air and Project Wing found the widest application in this area. Amazon's business model relies on labour-saving technology to increase their efficiency and effectiveness as online retailers. Google's aircraft is called a tailsitter, its takeoff is vertical, and then the flight continues in a horizontal position, which allows for greater control over steering and speed. The purpose is also to deliver goods, but the construction of the aircraft is different from Amazon's. [6].

Figure 13. *Amazon Prime Air [14]*

8 SMART CONCEPT

Smart technologies have been applied in various fields and have created many new and interesting research topics, e.g. smart manufacturing, smart city, smart house, smart agriculture, smart hospitality, smart shopping, etc.

8.1. Smart mobility

Smart mobility is a concept where travel time is optimized using different data from the past and in real time by IT and communication technologies, which results in a reduction of space consumption, road congestion, traffic accidents and harmful gas emissions. The Smart City concept and strategies are aimed at improving the existing services in cities, making the current infrastructure more suitable for participating citizens and ultimately enabling the sustainable development of the urban environment in the future.

8.2. Smart roads

Smart roads are an integral part of the smart city concept that applies advanced IT, such as the Internet of Things, Big Data and artificial intelligence, to facilitate the planning, construction, management and services of smart cities. Smart roads include the roads themselves, smart street lighting, smart traffic signs, and smart or autonomous cars that drive on those roads. The smart road system deployed in smart cities requires extensive sensor networks that generate huge amounts of data about traffic flow and public transport systems.

Figure 14*. Smart city, smart road, smart signs [23]*

9 MODERNISATION OF RAILWAY FREIGHT TRANSPORT

Railways need to be seen as resilient, market-responsive and future-oriented. According to experts, there are the following critical areas where railways could change their current state to stimulate innovation and growth. These are: faster automation, improved fuel efficiency, faster asset replacement, digital automatic connection.

9.1. Hyperloop

The Hyperloop is a train-like transport design that can reach revolutionary speeds. Hyperloop technology is still in development. The Hyperloop Transportation System (HTS) represents passenger capsules that move inside tubes in a low-resistance and low-pressure environment. They are then powered and guided by a caterpillar inside with the potential to move at near the speed of sound. The HTS concept is currently seen as a promising alternative to short-haul flights, where it can promise shorter travel times and lower fuel consumption.

Figure 15*. Hyperloop [25]*

9.2. Suspension railway

The German city of Wuppertal in the south of the Ruhr region near Düsseldorf is the greenest city in Germany. An inverted or suspended railway is an elevated monorail, in which the vehicle is suspended from a fixed track, built directly above waterways or roads. The train hangs under the rail and carries cargo or people. Since 2019, the wagons have been replaced by new "Generation 15" wagons. The unconventional public transportation system consists of about eight miles of monorail, six of which hang over the city.

Figure 16. *Suspension railway [26]*

10 MICROMOBILITY

Micromobility refers to small modes of transport, usually light, slow vehicles that travel below 30 miles per hour and are operated by one person. Partially or fully motorized, they are intended for short trips. In the context of future transport, these are affordable, rechargeable solutions that could be available as urban ride-sharing programs, some of which even exist today, such as e-bikes and e-scooters.

10.1. Nimbus One Microcar

The Nimbus One is a three-wheeled "autocycle" with a fully enclosed design that is one-quarter the size of a compact car. According to the company, the idea was to combine the nimble practicality of a motorcycle with the safety and comfort of a car. Smart body design gives the vehicle a rather sleek look while maximizing interior space as much as possible in a vehicle of this size

Figure 17*. Nimbus One [27]*

10.2. Robo-taxi

Robo-taxis, a type of shared autonomous taxis, could significantly reduce parking problems and levels of private car ownership. People can also save money on vehicle maintenance, repair and insurance costs by opting for Robo-taxi services. Many companies around the world have invested in the development of Robo-taxi technology. However, several barriers have been identified in the implementation of Robo-taxi services, such as technological barriers, regulatory barriers and costs. [3].

11 THE FUTURE OF WATER TRANSPORT

From autonomous cargo-carrying submarines to aircrafts and amphibious flying machines, these watercrafts will change the way we travel on waterways.

11.1. Fehmarn undersea tunnel

A new 18 km long undersea tunnel is being built to connect Germany and Denmark, and once completed, people will be able to travel between Puttgarden - on top of Fehmarn (the German island the tunnel is named after) - and the Danish port of Rødby in just 10 minutes by car, or 7 by train. Unlike other projects, the Fehmarn link will not be drilled under the seabed, but will sit on top of it, as a submerged tunnel that will be buried inside a trench dug into the seabed.

Figure 18. *Fehmarn Tunnel [28]*

11.2. The most unusual bridge in Europe

This bridge, located in the Öresund strait, which connects the Baltic and North Sea, is perhaps the most original in Europe. The Öresund strait is very narrow, and the ferry line in that place has been connecting the Swedish city of Malmo and Copenhagen, the capital of Denmark, for a long time. The bridge itself, opened to traffic in 2000, became the most original similar construction in Europe. The construction of this bridge contributed to a large increase in transport and had a positive impact on the development of the Copenhagen and Scania regions. It also contributes to a better connection between the Nordic countries and Central Europe. The project was completed in 2020.

***Figure 19**. Öresund Bridge [29]*

12 CONCLUSION

This paper presents some of the technologies that are widely used, as well as those that will appear in the future. At the beginning of the paper, it has been explained what an intelligent transport system actually is. The next section is about electrification. There are many advantages of electric vehicles compared to classic ones with internal combustion engine. The paper explains what autonomous vehicles are. It is believed that smart cars will be exclusively battery-powered autonomous vehicles and that the number of traffic accidents will be significantly reduced. Autonomous trucks are also mentioned later. What is also important to mention is the design of vehicles themselves. The main goals of designers are to reduce the noise caused by the wind hitting the body of the vehicle, and to increase the aerodynamics of the vehicle, so that the vehicle has as little resistance as possible when moving. According to scientists, the flying car revolution will be achieved by 2025 and will require new policies and standards to regulate the transition and handover periods between manual and autonomous vehicle control and the complex transition between ground and flight dynamics. The next section, referring to flying hotels that exist only in theory, describes the Sky Cruise Hotel and Driftscape. Section 7 has been conceptualized based on delivery drones. The last mile delivery concepts that are looming in the near future, and whose experimental phase is underway, are concepts that are based on technological development and innovation in either transport or handover. Further in the paper, smart technologies, applied in different areas, have been investigated. Smart mobility is a concept where travel time is optimized using different data from the past and in real time by IT and communication technologies, which results in a reduction of space consumption, road congestion, traffic accidents and harmful gas emissions. Railways need to be seen as resilient, market-responsive and future-oriented. Further in Section 9, modern trains and infrastructure that tend to follow all new changes are discussed. There is a tendency towards the introduction of magnetically levitated trains. Recently, micromobility has become more and more accessible and it offers users a flexible service, i.e. the use of vehicles in accordance with their needs. Finally, the last section refers to water transport. From autonomous cargo-carrying submarines to aircraft and amphibious flying machines, these watercrafts will change the way we travel on waterways, including modern tunnels, bridges and all accompanying equipment that is put into use every day.

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THE IMPACT OF STABILITY ON THE COMFORT OF MODERN RAILWAY TRANSPORT

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Abstract

This study focuses on analyzing the dynamic behavior and stability of vibrations in a complex mechanical oscillator moving on a three-part viscoelastically connected infinite continuous beam-foundation system. The instability, caused by elastic waves generated in the continuum structure by the moving oscillator, is relevant to high-speed trains and vehicle systems. The paper introduces an enhanced procedure and parametric analysis, emphasizing the impact of a proposed variable primary stiffness suspension. To handle the complex expressions in the model, the D-decomposition method and argument principle are employed. The analysis is centered around two main objectives: determining instability intervals for varying stiffness moduli in the primary suspension and obtaining significant conclusions from the results.

Keywords: *Instability; Varying stiffness; D-decomposition method; Principle of argument.*

1 INTRODUCTION

Vibrations of a vehicle that moves on a long elastic structure can become unstable due to elastic waves produced by the vehicle within the structure. A typical example of the vehicle that can experience such instability is a high-speed train. When this train moves at a considerable speed, it has the capacity to produce elastic waves in the railway track, which can destabilize the train's vibrations. This instability has the consequence of elevating vibration levels in both the train and the railway track, markedly diminishing passenger comfort and escalating the likelihood of track deterioration and train derailment (Fig. 1). The initial study of an infinite beam on an elastic foundation subjected to a concentrated moving force was presented by Timoshenko [1]. His groundwork has been followed and extended by many other researchers. Frýba [2] gives theoretical formulations for the problems of moving loads on continuous beams, beams on elastic foundations, frames, arches, etc., and Verichev and Metrikine [3] studied a rigid body travelling on a Timoshenko beam supported by an elastic foundation. Stojanović et al. [4] analyzed the vibration stability of a coupled bogie system moving uniformly along a complexly modeled flexibly supported infinite high-order shear deformable coupled beam system on a viscoelastic base. In present paper, a comprehensive investigation was carried out to analyze the dynamic behavior and stability of vibrations of a complexly coupled mechanical oscillator that moves on a long three-part viscoelastically connected infinite continuous beam-foundation system (Fig. 2). In this study, stability regions are determined for varying stiffness moduli of the primary suspension. A thorough stability analysis is conducted, and the stability regions are examined and discussed in relation to the varying stiffness of the primary suspension.

Fig. 1 *Train derailment*

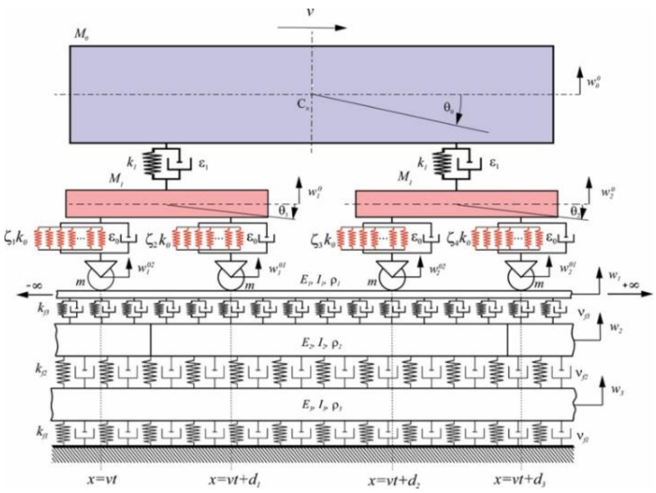

Fig. 2 *Complexly coupled mechanical oscillator*

2 MODELING OF THE RAILWAY VEHICLE SYSTEM

The model used as a complex foundation system can be seen in Fig. 2. In this representation, the rail functions as a supported infinite beam, while both the slab and the base are depicted as supported free beams. The connections of the track structure are represented by viscoelastic spring-damping elements. Using the high-order shear deformable

(Reddy-Bickford) beam theory, the interaction of the infinite coupled beam-layer mechanical system is defined by the following set of equations

$$\Psi_1 + k_{f3}(w_1 - w_2) + \nu_{f3}(\dot{w}_1 - \dot{w}_2) = p(x,t), \Phi_1 = 0, \quad (1)$$

$$\Psi_2 + k_{f2}(w_2 - w_3) - k_{f3}(w_1 - w_2) + \nu_{f2}(\dot{w}_2 - \dot{w}_3) - \nu_{f3}(\dot{w}_1 - \dot{w}_2) = 0, \quad \Phi_2 = 0, \quad (2)$$

$$\Psi_3 + k_{f1}w_3 - k_{f2}(w_2 - w_3) + \nu_{f1}\dot{w}_3 - \nu_{f2}(\dot{w}_2 - \dot{w}_3) = 0, \quad \Phi_3 = 0, \quad (3)$$

where

$$\Psi_i = C_{i1}\ddot{w}_i - C_{i2}(\varphi_i' + w_i'') - C_{i3}\ddot{w}_i'' + C_{i4}w_i^{(4)} + C_{i5}\ddot{\varphi}_i' + C_{i6}\varphi_i''', \quad (4)$$

$$\Phi_i = D_{i1}\ddot{\varphi}_i - D_{i2}\varphi_i'' + D_{i3}(\varphi_i + w_i') + D_{i4}\ddot{w}_i' + D_{i5}w_i''', \quad i = 1,2,3, \quad (5)$$

where C_{ik}, D_{ij} are constants obtained and documented in [4] and $p(x,t)$ represents the reaction of the bogie system presented in Fig. 2

$$p(x,t) = -\delta(x - vt - d_3)\left(m\frac{d^2w_2^{01}}{dt^2} + \left[\zeta_4 k_0\left(w_2^{01} - w_2^0 + \theta_2\frac{d_L}{2}\right) + \epsilon_0\frac{d}{dt}\left(w_2^{01} - w_2^0 + \theta_2\frac{d_L}{2}\right)\right]\right)$$
$$-\delta(x - vt - d_2)\left(m\frac{d^2w_2^{02}}{dt^2} + \left[\zeta_3 k_0\left(w_2^{02} - w_2^0 - \theta_2\frac{d_L}{2}\right) + \epsilon_0\frac{d}{dt}\left(w_2^{02} - w_2^0 - \theta_2\frac{d_L}{2}\right)\right]\right)$$
$$-\delta(x - vt - d_1)\left(m\frac{d^2w_1^{01}}{dt^2} + \left[\zeta_2 k_0\left(w_1^{01} - w_1^0 + \theta_1\frac{d_L}{2}\right) + \epsilon_0\frac{d}{dt}\left(w_1^{01} - w_1^0 + \theta_1\frac{d_L}{2}\right)\right]\right)$$
$$-\delta(x - vt)\left(m\frac{d^2w_1^{02}}{dt^2} + \left[\zeta_1 k_0\left(w_1^{02} - w_1^0 - \theta_1\frac{d_L}{2}\right) + \epsilon_0\frac{d}{dt}\left(w_1^{02} - w_1^0 - \theta_1\frac{d_L}{2}\right)\right]\right)$$

$w_i(x,t)$ is the vertical deflection of the beam; $w_1^{01}(t)$, $w_1^{02}(t)$, $w_2^{01}(t)$, $w_2^{02}(t)$, are the vertical displacements of the masses (wheels); $w_1^0(t)$, $w_2^0(t)$ are the vertical displacements of the centers of mass of the bars that represent the bogies' bodies, and $w_0^0(t)$ is the vertical displacement of the bar that represents the car's body, $\varphi_i(x,t)$ is the rotation angle of the beams' cross-section; θ_0, θ_1, and θ_2 are the angles of rotation of the bars around their centers of mass. The physical properties are presented with: M_0, M_1 and J_0, J_1 are the masses and moments of inertia of the bars; k_{fi} and ν_{fi} are the stiffness moduli and the viscosity shear moduli of the foundation per unit length; k_0 and ϵ_0 are the stiffness modulus and the damping factor of the primary suspension; k_1 and ϵ_1 are the stiffness modulus and the damping factor of the secondary suspension. The Dirac delta-function is designated with $\delta()$. The factors ζ_1, ζ_2, ζ_3, and ζ_4 are multipliers for the stiffness modulus of the primary suspension and the following notation is used $\ddot{w}_i = \frac{\partial^2 w_i}{\partial t^2}$, $w_i' = \frac{\partial w_i}{\partial x}$, $w_i'' = \frac{\partial^2 w_i}{\partial x^2}$, $\ddot{\varphi}_i = \frac{\partial^2 w_i}{\partial t^2}$, $\varphi_i' = \frac{\partial w_i}{\partial x}$, $\varphi_i'' = \frac{\partial^2 w_i}{\partial x^2}$. With the (1-3), the following set of equations represent the full form of the dynamic equilibrium of the system presented in Fig. 2

$$M_1\frac{d^2w_2^0}{dt^2} - \left[\zeta_4 k_0\left(w_2^{01} - w_2^0 + \theta_2\frac{d_L}{2}\right) + \epsilon_0\frac{d}{dt}\left(w_2^{01} - w_2^0 + \theta_2\frac{d_L}{2}\right)\right] - \left[\zeta_3 k_0\left(w_2^{02} - w_2^0 - \theta_2\frac{d_L}{2}\right) + \epsilon_0\frac{d}{dt}\left(w_2^{02} - w_2^0 - \theta_2\frac{d_L}{2}\right)\right] + k_1\left[\left(w_2^0 - w_0^0 + \theta_0\frac{d_{L0}}{2}\right) + \epsilon_1\frac{d}{dt}\left(w_2^0 - w_0^0 + \theta_0\frac{d_{L0}}{2}\right)\right] = 0,$$

$$J_1\frac{d^2\theta_2}{dt^2} + \left[\zeta_4 k_0\left(w_2^{01} - w_2^0 + \theta_2\frac{d_L}{2}\right) + \epsilon_0\frac{d}{dt}\left(w_2^{01} - w_2^0 + \theta_2\frac{d_L}{2}\right)\right]\frac{d_L}{2} - \left[\zeta_3 k_0\left(w_2^{02} - w_2^0 - \theta_2\frac{d_L}{2}\right) + \epsilon_0\frac{d}{dt}\left(w_2^{02} - w_2^0 - \theta_2\frac{d_L}{2}\right)\right]\frac{d_L}{2} = 0,$$

$$M_1\frac{d^2w_1^0}{dt^2} - \left[\zeta_2 k_0\left(w_1^{01} - w_1^0 + \theta_1\frac{d_L}{2}\right) + \epsilon_0\frac{d}{dt}\left(w_1^{01} - w_1^0 + \theta_1\frac{d_L}{2}\right)\right] - \left[\zeta_1 k_0\left(w_1^{02} - w_1^0 - \theta_1\frac{d_L}{2}\right) + \epsilon_0\frac{d}{dt}\left(w_1^{02} - w_1^0 - \theta_1\frac{d_L}{2}\right)\right] + k_1\left[\left(w_1^0 - w_0^0 - \theta_0\frac{d_{L0}}{2}\right) + \epsilon_1\frac{d}{dt}\left(w_1^0 - w_0^0 - \theta_0\frac{d_{L0}}{2}\right)\right] = 0,$$

$$J_1\frac{d^2\theta_1}{dt^2} + \left[\zeta_2 k_0\left(w_1^{01} - w_1^0 + \theta_1\frac{d_L}{2}\right) + \epsilon_0\frac{d}{dt}\left(w_1^{01} - w_1^0 + \theta_1\frac{d_L}{2}\right)\right]\frac{d_L}{2} - \left[\zeta_1 k_0\left(w_1^{02} - w_1^0 - \theta_1\frac{d_L}{2}\right) + \epsilon_0\frac{d}{dt}\left(w_1^{02} - w_1^0 - \theta_1\frac{d_L}{2}\right)\right]\frac{d_L}{2} = 0,$$

$$M_0\frac{d^2w_0^0}{dt^2} - \left[k_1\left(w_1^0 - w_0^0 - \theta_0\frac{d_{L0}}{2}\right) + \epsilon_1\frac{d}{dt}\left(w_1^0 - w_0^0 - \theta_0\frac{d_{L0}}{2}\right)\right] - \left[k_1\left(w_2^0 - w_0^0 + \theta_0\frac{d_{L0}}{2}\right) + \epsilon_1\frac{d}{dt}\left(w_2^0 - w_0^0 + \theta_0\frac{d_{L0}}{2}\right)\right] = 0,$$

$$J_0\frac{d^2\theta_0}{dt^2} + \left[k_1\left(w_2^0 - w_0^0 + \theta_0\frac{d_{L0}}{2}\right) + \epsilon_1\frac{d}{dt}\left(w_2^0 - w_0^0 + \theta_0\frac{d_{L0}}{2}\right)\right]\frac{d_{L0}}{2} - \left[k_1\left(w_1^0 - w_0^0 - \theta_0\frac{d_{L0}}{2}\right) + \epsilon_1\frac{d}{dt}\left(w_1^0 - w_0^0 - \theta_0\frac{d_{L0}}{2}\right)\right]\frac{d_{L0}}{2} = 0, \quad (6)$$

$$w_2^{01}(t) = w(vt + d_3, t), \quad w_2^{02}(t) = w(vt + d_2, t),$$
$$w_1^{01}(t) = w(vt + d_1, t), \quad w_1^{02}(t) = w(vt, t),$$
$$\lim_{|x-vt|\to\infty} w_i(x,t) = 0, \quad \lim_{|x-vt|\to\infty} \varphi_i(x,t) = 0, \quad (7)$$

By using a moving reference system $\xi = x - vt$ the previous equations can be rewritten. It is then feasible to analyze the characteristic equation of vibrations by applying integral transforms to the modified system of equations

$$W_{si}(\xi,s) = \int_0^\infty w_i(\xi,t)\,e^{-st}\,dt,$$

$$\Phi_{si}(\xi,s) = \int_0^\infty \varphi_i(\xi,t)\,e^{-st}\,dt,$$

$$\widehat{W}_{k,si}(k,s) = \int_{-\infty}^{\infty} W_{si}(\xi,s)e^{-ik\xi}\,d\xi,$$

$$\widehat{\Phi}_{si}(k,s) = \int_{-\infty}^{\infty} \Phi_{si}(\xi,s)e^{-ik\xi}\,d\xi,$$

$$W_1^{01}(s) = \int_0^{\infty} w_1^{01}(t)e^{-st}\,dt,\quad W_1^{02}(s) = \int_0^{\infty} w_1^{02}(t)e^{-st}\,dt,$$

$$W_2^{01}(s) = \int_0^{\infty} w_2^{01}(t)e^{-st}\,dt,\quad W_2^{02}(s) = \int_0^{\infty} w_2^{02}(t)e^{-st}\,dt,$$

$$W_0^{0}(s) = \int_0^{\infty} w_0^{0}(t)e^{-st}\,dt,\quad W_1^{0}(s) = \int_0^{\infty} w_1^{0}(t)e^{-st}\,dt,$$

$$W_2^{0}(s) = \int_0^{\infty} w_2^{0}(t)e^{-st}\,dt,$$

$$\Theta_0 = \Theta_0(s) = \int_0^{\infty} \theta_0(t)e^{-st}\,dt, \Theta_1 = \Theta_1(s) = \int_0^{\infty} \theta_1(t)e^{-st}\,dt,$$

$$\Theta_2 = \Theta_2(s) = \int_0^{\infty} \theta_2(t)e^{-st}\,dt. \tag{8}$$

Presuming that the initial conditions are insignificant (the initial conditions do not have an impact on the system stability because the governing equations are linear), and considering that $W_1^{02}(s) = W(0,s)$, $W_1^{01}(s) = W(d_1,s)$, $W_2^{02}(s) = W(d_2,s)$, $W_2^{01}(s) = W(d_3,s)$, the application of the transforms results in the system of algebraic equations. Starting from that system of algebraic equations and applying to it the inverse Fourier transform over k, then eliminating W_0^0, W_1^0, W_2^0, Θ_0, Θ_1, Θ_2, and setting the values $\xi = 0$, $\xi = d_1$, $\xi = d_2$, $\xi = d_3$, subsequently, will produce a system of algebraic equations—with respect to the Laplace-displacements of the contact points $w_s(0,s)$, $w_s(d_1,s)$, $w_s(d_2,s)$, $w_s(d_3,s)$

$$\mathbf{G} \cdot \mathbf{w}_s[(0,d_1,d_2,d_3),s] = 0$$

$$\Leftrightarrow$$

$$\begin{bmatrix} g_{11} & \cdots & g_{14} \\ \vdots & \ddots & \vdots \\ g_{41} & \cdots & g_{44} \end{bmatrix} \begin{Bmatrix} w_s(0,s) \\ w_s(d_1,s) \\ w_s(d_2,s) \\ w_s(d_3,s) \end{Bmatrix} = \begin{Bmatrix} 0 \\ 0 \\ 0 \\ 0 \end{Bmatrix}. \tag{9}$$

System of algebraic equations obtained possesses a non-trivial solution provided that the determinant of the matrix $\mathbf{G}$ satisfies the condition

$$\det \mathbf{G} = 0. \tag{10}$$

The stability of the model is analyzed by investigating the eigenvalues of the characteristic equation (10). If at least one root of the characteristic Eq. (10) has a positive real part, then the vibrations of the complex moving oscillator are unstable—hence, that is the criterion for determining the instability of vibrations. The mentioned equation is an integral equation with respect to the Laplace variables. To solve the presented mathematical problem more easily, the D-decomposition method is applied. The use of the D-decomposition method allows ascertainment of a relative variation of the number of unstable roots depending on the stiffness k_0, but not the number itself. Thus, finding the number of unstable roots for any single value of stiffness k_0 is what remains to be done. This can be achieved by using the argument principle. Parametric analyses are performed for the super-critical case when the complex moving oscillator system's velocity is higher than the certain critical velocity.

3 RESULTS AND DISCUSSION

The D-decomposition curves are obtained for the same set of model parameters as used in [5]. The referent case (referred to as Case 1) is chosen to represent the traditional system of primary suspension, where all four suspension supports have the same stiffness, denoted as k_0 and defined through factors $\zeta_1 = \zeta_2 = \zeta_3 = \zeta_4 = 1$. Other cases with different values for these factors, and consequently different stiffness moduli for each support, are detailed in Table 1. The D-decomposition curves and the number of unstable roots is calculated for the supercritical velocity with a value of $v = 1.12\ v_{cr}$.

Table 1 Varying non-dimensional parameter of the primary suspension

Varying factor	ξ_1	ξ_2	ξ_3	ξ_4
Case1	1	1	1	1
Case 2	8	1	1	1
Case 3	1	8	1	8
Case 4	1	8	1	4

Fig. 3 is the integrated diagram obtained D-decomposition curves for the referent case and it present the regions with the number of unstable roots. Table 2 shows the number of unstable roots for each real k_0 interval. It can be noticed that the stable region (without unstable roots) is included in the stiffness region $k_0 \in (3.067, 5.074) \times 10^7$ N/m.

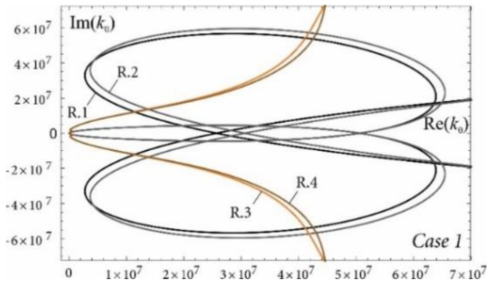

Fig. 3 *D-decomposition curves ($v = 1.12\ v_{cr}$) according to the set of parameters for Case 1*

Table 2 Review of instability regions

$k_0 \times 10^7$ [N/m]	0	2.573	3.067	5.074	5.076	$+\infty$
Case1	4	2	0	4	4	

In case 2 where the first suspension possesses the higher stiffness $\zeta_1 = 8$ and other factors are the same $\zeta_2 = \zeta_3 = \zeta_4 = 1$, the stable region (the region that lacks unstable roots) exists in the stiffness region $k_0 \in (2.837, 4.590) \times 10^7$ N/m; the numbers of unstable roots for this case are shown in Table 3, and the D-decomposition curves are illustrated in Fig. 4. A comparison between Case 1 and Case 2 reveals that the region of stability is broader in the referent Case 1, but in Case 2, it begins at a lower stiffness value. The observed contrast between Case 1 and Case 2 suggests that the proposed model with asymmetric suspension offers advantages by allowing the adjustment of stable regions through changes in the symmetry of the primary suspension, a feature that could prove useful in technical applications.

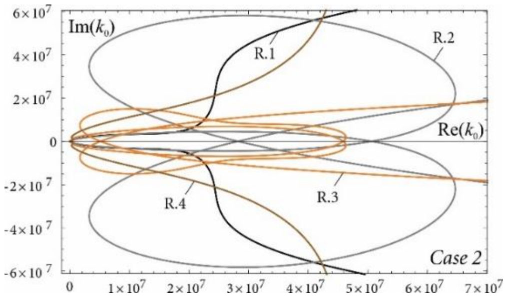

Fig. 4 *D-decomposition curves ($v = 1.12\ v_{cr}$) according to the set of parameters for Case 2*

Table 3 Review of instability regions

$k_0 \times 10^7$ [N/m]	0	0.515	2.837	4.590	5.079	+∞
Case 2	4	2	0	2	4	

In Case 3, ζ factors are chosen to alternate $\zeta_1 = \zeta_3 = 8$ and $\zeta_2 = \zeta_4 = 1$; the complete stable region belongs to the region of stiffness $k_0 \in (0.557,\ 4.565) \times 10^7$ N/m. Comparison with the referent Case 1 shows that Case 3 possesses a considerably larger region of stability, at the lower stiffness range. (Table 4, Fig. 5)

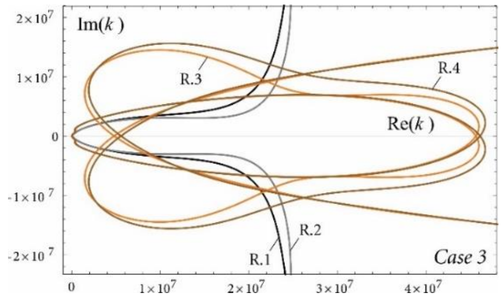

Fig. 5 *D-decomposition curves ($v = 1.12\ v_{cr}$) according to the set of parameters for Case 3*

Table 4 Review of instability regions

$k_0 \times 10^7$ [N/m]	0	0.479	0.557	4.565	4.614	+∞
Case 3	4	2	0	2	4	

In Case 4, stiffness factors also alternate, as in Case 3, but the stiffness of the last suspension is decreased. Results are presented in Table 5 and Fig. 6, and they show that Case 4 has advantages compared to Case 1 (the stable region begins at a lower stiffness k_0) but is not superior to Case 3, which is larger and completely covers the stable region of Case 4.

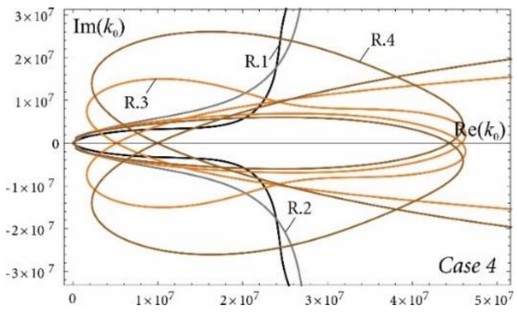

Fig. 6 *D-decomposition curves ($v = 1.12\ v_{cr}$) according to the set of parameters for Case 4*

Table 5 Review of instability regions

$k_0 \times 10^7$ [N/m]	0	0.515	1.001	4.445	4.584	+∞
Case 4	4	2	0	2	4	

4 CONCLUSION

This paper discusses the stability of vibrations of a complex moving oscillator that is moving along a continuous and infinite complex three-part viscoelastic beam-foundation system. The parametric study of the stability domain was done with a focus on the primary suspension and different combinations of stiffness factors. The stability of four chosen cases was calculated using the D-decomposition method and the argument principle. The stability zones have been discovered and reported in tabular form for each considered case, and later discussed

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HYBRID WASTE COLLECTION SYSTEM

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Abstract

The paper presents the technology of collecting and transporting municipal waste in urban areas. The research contribution of this work refers to the application of information and communication technologies in the waste collection and transportation system in the city of Niš. The current state of municipal waste collection in the city was analyzed and, based on the analysis, a prototype of a hybrid waste collection system was presented, which should be a subsystem of a smart city.

***Keywords**: vehicle routing optimization, smart waste collection*

1 INTRODUCTION

Waste collection in urban areas is a very complex system and is very attractive for research. The main reason is that companies for the collection of communal waste - UPC are increasingly facing high transport costs and highly inefficient use of their resources in their work. The most common reason for these deficiencies is that municipal waste collection vehicles often visit waste receptacles that are only partially filled. The routes of waste collection vehicles are mostly deterministic, that is, the vehicles move along pre-defined routes, regardless of whether the waste containers are full.

The amounts of municipal waste are mostly stochastic in nature, and the accumulation of waste depends on several factors. Some of the more important factors are seasons, holidays, sports and cultural events, etc. Certain studies indicate that only about 40% of municipal waste is collected from containers whose level of filling is greater than 75% [1]. All this shows that the waste collection system should be implemented much more efficiently. One of the ways to develop the most efficient waste collection model is the application of modern information and communication technologies. The application of such technologies in the system of waste collection in urban areas contributes to the reduction of transport costs of the UPC as well as a more rational use of resources [2, 3]. The goal of this work is to present a hybrid system of municipal waste collection in the city of Niš with the application of modern information and communication technologies.In addition to numerous researches that have been conducted with the aim of optimizing the municipal waste collection system, the development of smart cities shows that there is still a lot of room for improving the waste management system [4, 5].

2 WASTE COLLECTION SYSTEM IN NIŠ

Uncontrolled disposal of communal waste on unorganized surfaces is one of the biggest sources of environmental pollution (water, soil, air) and a health hazard for all living organisms. This is another reason for finding the most efficient municipal waste management system. In the Niš region, each municipality organizes its own waste collection services independently, through public utility companies, with little inter-municipal cooperation. At the same time, these public utilities are mostly not only engaged in waste management, but also have other utilities under their jurisdiction (water supply, cemeteries, markets). There is also the problem of scarce vehicle fleets where a large number of waste collection vehicles are outdated. Waste collection is done mainly in urban areas.The entire territory of the city of Niš is, from the point of view of waste collection, divided into 30 regions. Depending on the containers for waste disposal, two groups of regions are distinguished:

- areas for waste collection in bins,
- waste collection areas in containers.

The first group includes 17 regions for users who dispose of municipal waste in bins with a volume of 80-120l. The waste removal service for these users is performed once a week. One region has three region-days. The second group includes 13 regions for users who use containers for municipal waste disposal. The waste collection service is usually carried out twice a week. The city landfill is located in Bubanj, 6 km from the city center and covers an area of 31.08 ha. Waste disposal technology is layered spreading and partial compaction of layers of waste and a covering layer of inert material. Extraction of secondary raw materials is in a very small percentage. Based on this, it can be concluded that classic waste collection technologies are applied in the area of the city of Niš. This means that the vehicles receive travel routes in advance, which we have already mentioned that in this case there is a large underutilization of the vehicles, and thus the transport costs increase.The first way to improve the waste collection system is to optimize movement routes. This kind of problem is known in the literature as the vehicle routing problem. In their works, Marković et al. [6, 7] show that with the application of advanced algorithms, great savings can be achieved. However, in order to achieve even greater savings, that is, to create the most optimal models of the municipal waste collection system, it is necessary to use as much as possible the so-called smart technologies.

3 SMART WASTE MANAGEMENT

A smart city is a city or settlement that uses advanced information and communication technologies (ICT) and innovation to make its infrastructure, services, and functions more efficient, sustainable, and livable. A smart city uses sensors, data and communication networks to better manage resources, respond to the needs of citizens, improve the quality of life, and reduce the negative impact on the environment [4]. Such cities aim to be smart and sustainable in all aspects, including transportation, energy management, healthcare, education.

Widespread and inexpensive availability of cloud computing services, rapid penetration of smart phones in urbanpopulations as well as the rise of Internet of Things (IoT) inthe form of deployment of a variety of sensors drive smartcity technologies that offer new application domains in cityplanning and operations. IoT refers to the use of network protocols to form a universal network of interconnected things,that are not necessarily considered as computers. It is projected that there will be 34 billion connected things in theworld in 2020 [8], and the IoT will dominate the smart citytechnologies.Waste management is a partwaste collection systems has been a topic of interest in operations research and it has been demonstrated that optimizedroute planning and scheduling in waste collection can leadto significant cost reductions. Consequently, route optimization has been the main motivation for developing smartwaste collection systems. There are some studies of monitoring smart bins, where the authors present monitoring solutions based on radio frequency identification (RFID).

The system utilizes load sensors to estimate theaccumulated weight in the trash bins, and relays the datato collectors' pocket PC's (PDA). Collected data is then uploaded to an online database for further processing and analysis.In [9], authors present an IoT based smart garbage system, that utilizes pay-as-you-throw - PAYT model for food waste management. The system proposes custom-designed household garbage bins that are equipped with load sensorsand cellular Internet modules. The system is tested through a pilot study in Seoul, Korea, and authors underline that the power consumption (battery-based operation) is the maintrade-off of the system. In [10], authors emphasize that "an efficient, cost effective and environment friendly solution for real time bin status monitoring, collection and transportation of municipal solid waste is still a major challenge to the local municipal authorities" and propose a theoretical model using rule based decision algorithms.

3.1 Smart container for collecting municipal waste

The prototype of a smart container for municipal waste collection presented in this paper supports GPS/GPRS and includes sensors for data collection. The proposed system allows the status of the municipal waste container to be monitored in real time. The smart vessel consists of the following elements (fig 1): standard underground container, solar panel, ultrasonic sensor, GPS and GPRS modem. The solar panel is used to charge the battery located under the cover, from which the system receives energy. The battery capacity needs to be defined in relation to the requirements of the case study.The ultrasonic sensor measures the filling level of the container using ultrasonic beams. These sensors can monitor any type of waste (mixed waste, paper, plastic, glass, clothing, bio-waste, liquids, electronics, metal...) in bins and containers of different types and sizes. Ultrasonic technology ensures high and reliable measurement accuracy. Sensors can be connected to several (IoT) networks or GPRS to provide fast data transfer. An ultrasonic sensor is placed under the lid of the waste container and measures the filling level, regardless of what is deposited inside.

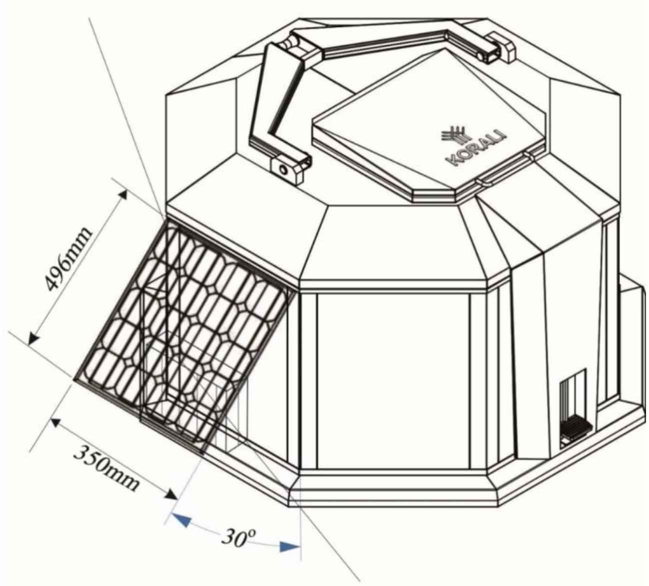

Fig. 1*Prototype of a smart container for municipal waste*

Fig. 2*Ultrasonic sensor JSN-SR04T V2.0*

To measure the level of filling in the prototype of the storage tank in this work, an ultrasonic sensor or a long-range transducer type JSN-SR04T V2.0 (fig. 2) is used. This type is a waterproof ultrasonic sensor that contains a non-contact distance measurement module and provides high accuracy. This ultrasonic sensor detects objects from 20 cm to 600 cm with an accuracy of 3 mm and a measuring angle of 20◦. Also, another important feature of this sensor is its operation at temperatures from -20 to +70 degrees Celsius.This proposal of a smart container is designed in such a way that it gives an estimated filling of the container with waste (fig. 3).

In many works, you can find systems that, in addition to the fullness of the container, also provide information about the mass of waste in the container as well as the current temperature in the container itself.Wireless sensor networks have become a key element in the sensor development process for smart waste systems.

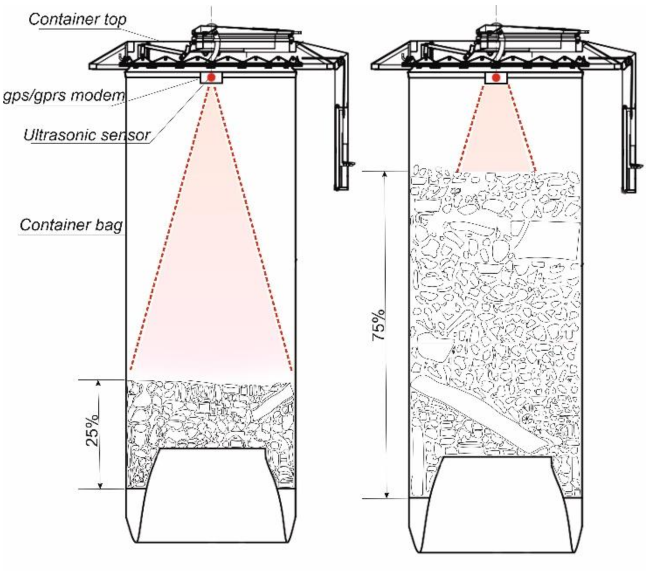

Fig. 3 *Prototype of a smart container with ultrasonic sensor*

Apart from the various transducers used to measure the data, one of the main purposes of the sensor is to establish a level of communication that is effective over the greatest possible distance. Data transmission from the sensors that have been collected are sent via gprs to the cloud where they are temporarily stored. The data is downloaded from the cloud and processed in order to obtain the real condition of the filling of containers at predefined locations. Figure 4 shows the communication of the smart container prototype with the master dispatcher via the cloud and after processing the data, the data is forwarded to the municipal waste collection vehicles.

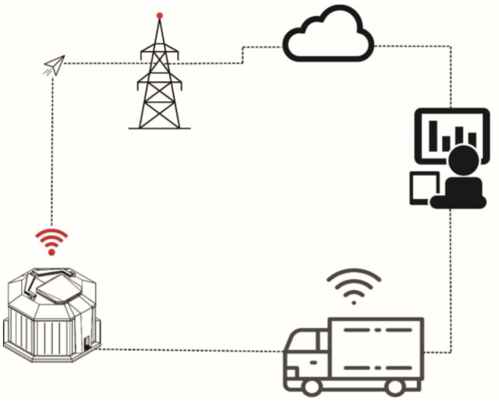

Fig. 4 *Information flow diagram from smart container to vehicles*

3.2 Route optimization

Regarding the choice of the waste collection route in the smart waste system, the search for optimal waste collection routes is considered an optimization problem that requires the reduction of collection costs and time. These costs relate to the distance traveled by each vehicle for waste and the number of vehicles required. This type of problem is known in the literature as the Vehicle Routing Problem (VRP). This name is used for a whole class of problems whose goal is to find a large number of routes for a group of vehicles located in a depot.The original VRP is also known as the capacity vehicle routing problem (CVRP) and includes constraints, for example, each vehicle in a fleet has a permanent and uniform load and there is one depot.The original problem has several variants [11] that add constraints on the real-life problem.

Figure 5 shows the classical CVRP approach with a homogeneous fleet. With CVRP, it is assumed that the vehicles are identical-homogeneous (equal capacity) and have a common starting point, and the only limitation that exists is the vehicle capacity. The objective function expresses the requirement to minimize the total cost (eg weight function of the number of routes and their total length or time) when serving all users [7].

CVRP can be expressed using basic notations from the theory of transport networks as follows. Let the transport network be defined asG=(V, A), whereV= {0,...,n,} a A is a set of branches. V is expensive(V = {0, 1, 2, . . . , n}) which defines the number of containers on the transport network. Each branch in set A has an associated cost (non-negative). Each container location from the pool{1, . . . , n} has a certain demand (in this case, the amount of waste) that must be collected and transported to the depot. Depot demand is always 0. A set (m) of vehicles of the same capacity (Q) (if the fleet has different capacities, the problem would be a different type of VRP problem) must be employed to collect waste from n container locations, m vehicles must start and finish their routes in storage.A route is defined as a cycle of the lower cost graph (G) that passes through the depot and the total demand of the vertex set must not exceed the total vehicle capacity. The purpose of the problem is to minimize the distance, time, or cost of m vehicles while meeting the following requirements: (1) the depot is the start and end point of each route; (2) each container location may be visited only once by one vehicle; and (3) the total demand of each route does not exceed the capacity (Q).

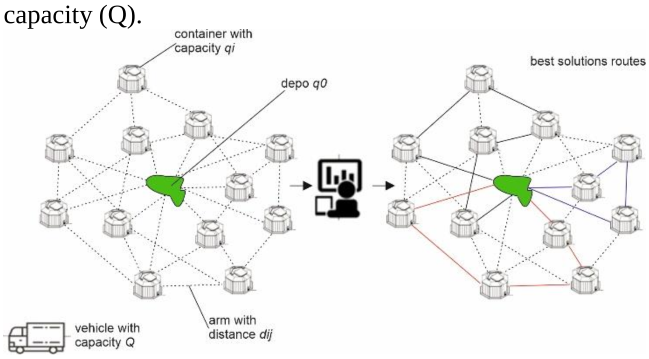

Fig. 5 *Graphic representation of CVRP*

Numerous methods can be found in the literature for solving CVRP, which belongs to the group of NP-hard problems. The quality of the CVRP solution most often depends on the quality of the definition of the transport network, and considering the complexity of the problem, heuristic and metaheuristic methods are most often used to solve it. Heuristic methods perform a limited exploration of the search space and usually deliver good quality results in small computing times and meta Heuristic methods are generic methods of exploration in the solution space for searching and optimization problems.

These methods provide a design line adaptable to each context, and they can generate more efficient algorithms [12]. In the continuation of this part, the focus will be on the presentation of the hybrid system for the optimization of municipal waste collection routes, that is, on the collection, storage, processing and sensor data. In relation to Figure 4, which shows the information flow and communication subsystems, Figure 6 indicates which of them are part of the optimization of the municipal waste collection route. The optimization process consists of 4 steps:

1. Container selection: the containers visited by the waste collection vehicle are selected from the defined transport network. The selection of containers is based on the fulfillment criteria of each container from the transport network. A threshold will be established to select the nodes that must be collected. The criterion that is set in this case is the fulfillment of 75%.
2. CVRP data: once the container fill data is obtained from the transport network nodes and their locations, the geographic information of each node is loaded from the geographic information subsystem to obtain the distance matrix that will be used to apply CVRP.
3. CVRP solver: based on the data obtained from the previous step and by defining a heuristic algorithm, problem solving is approached, that is, the design of routes for municipal waste collection.
4. **Best solution found**: after the best or most favorable solution is found (during the specified time under the stopping criterion), it is forwarded to the vehicle operator. The data persistence subsystem receives information and stores the collection plan solution for that day.

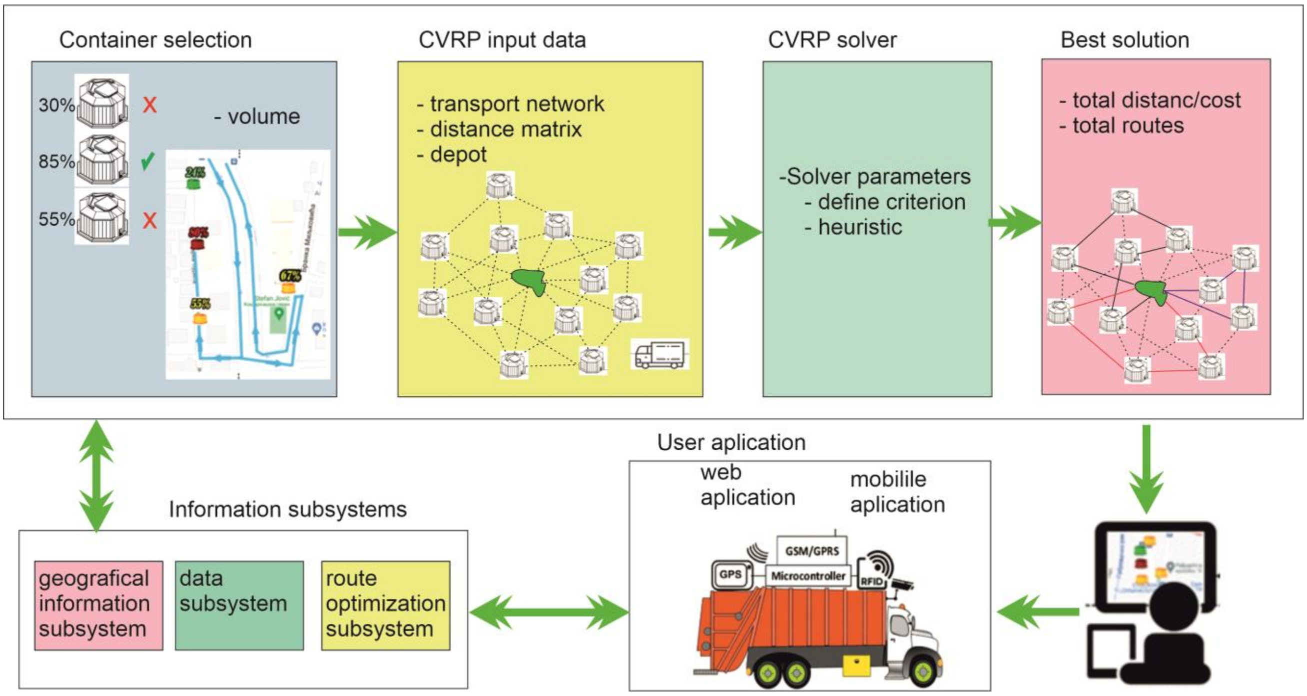

Fig. 6*Hybrid optimization rout flowchart*

4. CONCLUSIONS

The optimization of routes contributes, in addition to reducing transport costs, to the reduction of exhaust gases and fuel consumption, which is of great importance for the protection of air and the environment.Optimal vehicle movement routes minimize transport costs, which significantly affects the economy and profitability of waste collection companies. This optimization also contributes to the aesthetics of the city environment itself, because the number of vehicle passes and the time spent passing through populated areas are reduced, which affects the general appearance of the city and the quality of life of citizens.By using sensors and automating the municipal waste collection process, a high degree of efficiency and precision is achieved in the planning and execution of operations. Such automation significantly improves the work of waste collection companies, thus facilitating and speeding up the entire process, while reducing the so-called emptymoves.
The moves. The development of sucha system represents the future of the development of the city of Niš, which is already entering the process of implementing smart systems.

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THE INFLUENCE OF SOME STANDARDIZED AND NON-STANDARDIZED BIODIESEL CHARACTERISTICS ON FUEL QUALITY AND DIESEL ENGINE PERFORMANCE

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Abstract

Different raw material bases and different technological production processes can result in different biodiesel characteristics. In some research, biodiesels of unknown origin and characteristics are used or characteristics deviate from the standards prescribed. Even when biodiesels meet regulatory standards, it is possible for biodiesels to have different non-standard physico-chemical fuel characteristics that affect diesel engine performance. Testings are performed on different diesel engine types, with various fuel supply systems, various possibilities of regulating the engine operations and other different engine characteristics. All these leads to different assessments regarding the biodiesel usage as a diesel engine fuel. The paper provides an analysis of certain standardized and non-standardized characteristics of biodiesel and their impact on the quality of biodiesel and the operation of diesel engines when biodiesel is used as fuel.

Keywords: *biodiesel, standardized characteristics, non-standardized characteristics.*

1 INTRODUCTION

The requirements placed on biodiesel as a fuel for diesel engines relate to quality, availability, renewable raw materials for production, appropriate price and fulfillment of environmental requirements. The quality of biodiesel can be assessed through the compliance of biodiesel characteristics with the prescribed standards and the possibility that biodiesel has advantages or not major disadvantages compared to conventional diesel fuel. There are many raw materials from which biodiesel can be obtained [1]. The best results were achieved by chemical changes in vegetable oils, but biodiesel can also be obtained from wasted - already used and processed edible oil, as well as from the remains of animal fats. Based on their production technologies and development sustainability including all of the implemented influences and effects from cultivation to even after exploitation, biodiesels, like all biofuels in general, can be classified generationally [2, 3, 4, 5]. Producing biodiesel from different raw materials and different technological biodiesel production processes can result in different individual physical and chemical characteristics of fuel. The chemical procedure of esterification of vegetable oil with the aim of producing biodiesel, basically adds up to breaking down large and complex molecules into simpler, and in size smaller ones.

2 STANDARDIZED BIODIESEL CHARACTERISTICS

The quality and characteristics requirements that biodiesel must meet are defined by standards. There are, for example, ASTM D 6751 in the USA and EN 14214 in the EU. The current standard in the Republic of Serbia is SRPS EN 14214, which is identical to the corresponding one in the EU (Table 1).

Some comparative characteristics of diesel fuels and certain biodiesels obtained from various basic oils are shown in Table 2, based on [5] where the authors included and summarized numerous literatures on different types and characteristics of biodiesel used in research.

According to [6] the chemical formula of rapeseed oil methyl ester (MER) is $C_{21}H_{38}O_2$ with its molar mass of 323.4 g/mol, while, for example, according to [7] the chemical formula of MER is $C_{19}H_{35.2}O_2$ with its molar mass of around 296 g/mol, which is the consequence of the difference in the basic oil and in the process of esterification itself. The essence of esterification of rapeseed oil (and other biodiesel raw materials) lies in the breaking down of large and complex molecules of oil into simpler and in size smaller ones. It is precisely due to the importance of the degree of esterification that this value is prescribed by a standard – according to EN 14214 (Table 1) the degree of esterification should be at least 96.5 %. The kinematic viscosity of biodiesel is, for the examples from Table 2, in the range 3.7 to 5.8 mm^2/s and is slightly higher compared to diesel fuel (2 do 4.5 mm^2/s) but it is significantly smaller than for basic oil, which is also directly related to the degree of esterification. However, for some Palm, Jatropha and Karanja biodiesels (Table 2), higher kinematic viscosity values than those standardized by EN 14214 (Table 1) were observed. This can affect the the fuel delivery system operation, fuel injection process, injection fuel jet formation, mixture formation and biodiesel combustion, as well as emission characteristics.

Appropriate standards prescribe the same minimal values of the cetane number for both fuels (min 51). The higher the cetane number, the easier the ignition and the better the fuel combustion, which can affect the increase in engine power and the reduction of consumption. Furthermore, an increase in the degree of esterification causes an increase in the cetane number [7, 8]. For some biodiesels from Soya and Sunflower (Table 2) a slightly lower cetane number than standardized by EN 14214 was recorded. This should not be a problem because the addition of certain additives can increase the biodiesel cetane number, if necessary.

Table 1 Biodiesel standard EN 14214 [1]

Property	Unit	Test method	Limits	
			min	max
Density at 15 °C	kg/m^3	EN ISO 3675 EN ISO 12185	860	900
Viscosity at 40 °C	mm^2/s	EN ISO 3104	3.5	5.0
FAME content	% (m/m)	EN 14103	96.5	
Flash point	°C	EN ISO 2719 EN ISO 3679	101	
CFPP – Cold Filter Plugging Point [a)]	°C	EN 116		+5 summer -15 (-20) winter
Sulfur content	mg/kg	EN ISO 20846 EN ISO 20884 EN ISO 13023		10
Cetane number		EN ISO 5165	51	
Sulfated ash content	% (m/m)	ISO 3987		0.02
Water content	mg/kg	EN ISO12937		500
Total contamination	mg/kg	EN 12662		24
Copper strip corrosion (3h at 50 °C)	Rating	EN ISO 2160	class 1	
Acid value	mgKOH/g	EN 14104		0.5
Linolen. acid methyl ester	% (m/m)	EN 14103		12
Polyunsaturated methyl esters (≥ 4 double bonds)	% (m/m)	EN 15779		1
Group I metals (Na + K)	mg/kg	EN 14108 EN 14109 EN 14538		5
Group II metals (Ca + Mg)	mg/kg	EN 14538		5
Methanol content	% (m/m)	EN 14110		0.2
Monoglyceride content Diglyceride content Triglyceride content	% (m/m)	EN 14105		0.7 0.2 0.2
Free glycerol	% (m/m)	EN 14105 EN 14106		0.02
Total glycerol	% (m/m)	EN 14105		0.25
Phosphorus content	mg/kg	EN 14107 FprEN 16294		4
Iodine value	mg Iodine/100g	EN 14111 EN 16300		120
Oxidation stability (at 110 °C)	h	EN 14112 EN 15751	8.0	

a) Climate dependent requirements

It is important for fuel (especially for biofuels) that it does not form oxides (precipitate) in contact with air at high temperatures, so the standards define either the maximum amount of the same (less is better) or the minimum time (most often in the number of hours) for which the fuel shows the corresponding tkz. oxidation stability (higher is better). In terms of oxidation stability, biodiesel from palm and algae oil (for the largest number of species) show excellent results (Table 2). Biodiesels from rapeseed and soybeans can be said to be at an acceptable level, while sunflower, jatropha and karanja biodiesels more often have problems with oxidation stability (Table 2) and this should be kept in mind. The iodine value is an indicator of stability of biodiesel against oxidation. A biodiesel with a higher iodine value oxidizes more easily in contact with air and shows a greater tendency to polymerize and form residue in injectors and piston rings. The iodine value depends on the raw material from which biodiesel is produced and it is limited by various standards in different parts of the world – in the EU (EN 14214 – Table 1) and Japan it is maximally up to 120 (in the EU even up to 130 for biodiesel as fuel-oil), up to 140 in South Africa, not limited in Brazil, while in the USA, Australia and India it is not even included in the standards (so as not to exclude the raw materials such as soybean and sunflower oil from the production of biodiesel - for which two the values from Table 2 exceed the limit value according to EN 14214) [1, 5].

Table 2 Some comparative characteristics of certain biodiesels and diesel fuel [5]

Property	Diesel [a)]	Biodiesel from oil of:						
		Rapeseed	Soya	Sunflower	Palm	Jatropha	Karanja	Algae
Density (15 °C) (kg/m^3)	820-845	869-902	876-925	850-884	859-883	865-882	~894	820-890
Viscosity (40°C) (mm^2/s)	2-4.5	4.4-5.65	4.1-4.9	4.03-4.98	3.7-5.7	4.84-5.56	4.41-5.8	3.68-4.52
Flash point (°C)	min 56	166-179	171-195	89-187	167-176	170-191	114-168	>160
Cetane number	min 51	>51- 54	48-51.3	~49	59-64.6	51-52	50.8-54.5	51-65.5
Lower heating value (MJ/kg)	~42.5[b)]	36.3-38.2	36.7-38.4	36-38.4	36.3-37.5	38.5	35.9-37.9	33.3-36.5
Cold Filter Plugging Point CFPP (°C)	max +5 summer max -15 winter	-10 to -6	-7 to -2	-4 to -12	10 to14	~2	~3	-2.6 to -11.7
Cloud Point CP (°C)	max +3 summer max -5 winter	-3 to 8	0 to 1	-1 to 4	6 to 16	4-13	6-13.6	~-5
Iodine value (mgJ/100g)	-	97.4-114	120-133	~132	50 -59	~105	~83	65-109
Oxidation stability (110°C) (h)	min 20	~6.5	~7.1	0.8-2.7	~14.7	~2.3	~2.98	5.6-95.7

a)EN 590, b)[7]

As diesel fuel contains paraffins, at low temperatures their crystals first begin to separate, and the temperature at which the first crystals appear is called the Cloud Point (CP).

When the fuel starts to become cloudy due to the low temperature, it can still reach the engine. When the temperature is so low that the fuel can no longer pass through the fuel filter, we speak of the Cold Filter Plugging Point (CFPP). According to the EN 14214 standard, this temperature is +5 °C for summer or -15(-20) °C for winter biodiesel. Researchers often do not specify for which season (summer or winter) the biodiesels they use are for, but based on the researchers' region of origin, it can be concluded that CFPP and CP values are mostly within the required limits for biodiesels from Table 2, except for Palm oil biodiesel where CFPP values should be corrected with appropriate additives, and it is recommended to pay attention to this parameter for Jatropha and Karanja biodiesels.

Flash point as a parameter does not refer to the ignition point in the engine, but rather the temperature at which vapors that can be ignited are released from the fuel. According to the EN 590 standard for diesel fuel must be above 55 °C, while the minimum value for biodiesel (according to EN 14214) is 101 °C. This information is important for fire-safety during storage, distribution, etc. Biodiesels from Table 2 meet this requirement, except for certain Sunflower biodiesels.

Fuel density is a multiple important parameter. If we look at it through the amount of energy per volume unit of fuel, it would be important that the density of the fuel is as high as possible. However, fuels with a higher density than prescribed can cause problems in the fuel supply system operation, as well as have a negative impact on the fuel injection process, the quality of fuel atomization, the fuel spray formation, air-fuel mixtures, etc. [1]. Fuels with a lower density than prescribed by the standards can also cause problems in the fuel supply system operation. At the same time, it should be considered that diesel engines are set according to the characteristics of diesel fuel as a reference fuel. Also, the density is in direct connection with the fuel pressure wave speed in the fuel supply system and the fuel Bulk modulus [9]. The biodiesel injection characteristics can be improved by adding different additives [1, 10] or e.g., of ethanol [11].

3 NON- STANDARDIZED BIODIESEL CHARACTERISTICS

There are characteristics of biodiesel that are not standardized and can be very influential on the fuel supply system operation, fuel injection, etc. and generally to engine output characteristics and exhaust emissions. We certainly include the lower heating power of biodiesel, the proportion of oxygen in the composition of biodiesel, the fuel pressure wave speed (which is the speed of sound), Bulk modulus and surface tension.

The lower heating value of biodiesel is lower than the lower heating value of diesel fuel by approx. 10-15% and even up to 22% (for some Algae biodiesel) (Table 2). The consequences can be lower values of effective power and torque, more significant at higher engine speeds (5–10%), with an increase in effective specific fuel consumption by about 12% [12].

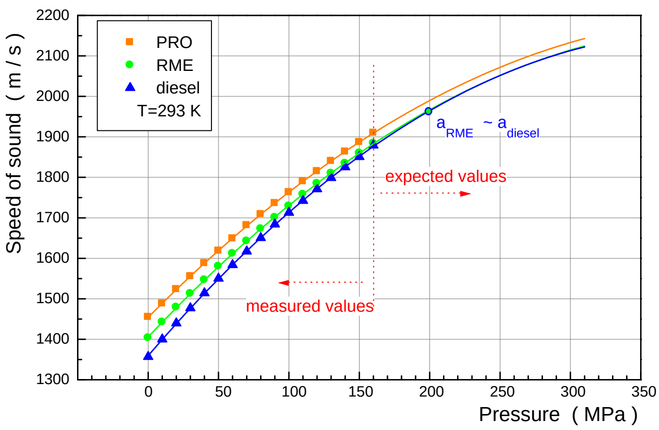


***Fig. 1** Speed of sound for tested fuels (PRO – pure rapeseed oil; RME – rapeseed biodiesel). Experimental values from atmospheric to 160 MPa and expected values for higher pressures [1,15]*

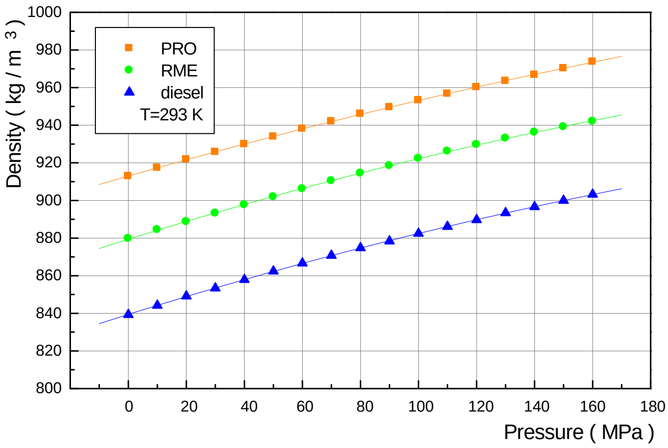


***Fig. 2** Density for tested fuels. Experimental values. [1,15]*

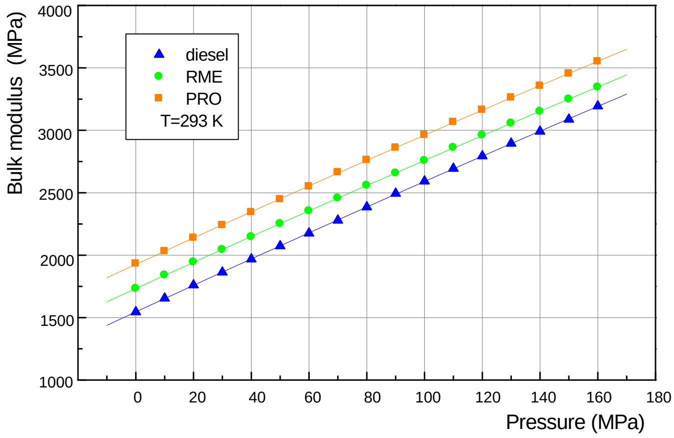


***Fig. 3** Bulk modulus for tested fuels calculated by experimental values of speed of sound and density [1,15]*

As a qualitatively significant fact about biodiesel as a diesel engine fuel, one can single out the mass ratio of oxygen at around 10% [13], i.e., 11–15% [14]. The presence of oxygen in the biodiesel composition is important from the perspective of combustion and partially compensates for the impact of the slightly lower heating value of biodiesel compared to diesel fuel.

The values of sound speed, Bulk modulus and surface tension of biodiesel (and diesel fuel) are very important for the fuel injection system operation, the injected fuel spray formation, combustion and exhaust emission quality. These values are different for biodiesel compared to diesel fuel. It is important to note that e.g., the values of sound speed, Bulk modulus and fuel density depend on the operating pressure (Fig. 1, 2, 3) and temperature [1,9,15]. For a diesel engine that is set to work with diesel fuel, this can be the cause of different fuel injection system operating parameters and beyond.

The consequences of the differences in bulk modulus, density and speed of sound (also viscosity and surface tension) of biodiesel (B100) and diesel fuel (and B50 mixture of 50% biodiesel and 50% diesel) lead to differences in the fuel injection system operation. The maximum pressure of p_I (pressure behind the high-pressure pump) is slightly higher when using B100 than that of diesel (D). Biodiesel maximum injection pressure p_{II} (fuel pressure before the fuel injector) is higher compared to D (Fig. 3) [1]. The larger differences are at higher loads.

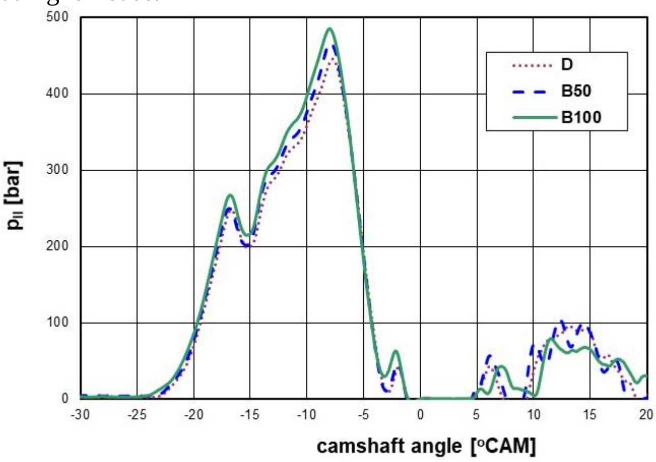
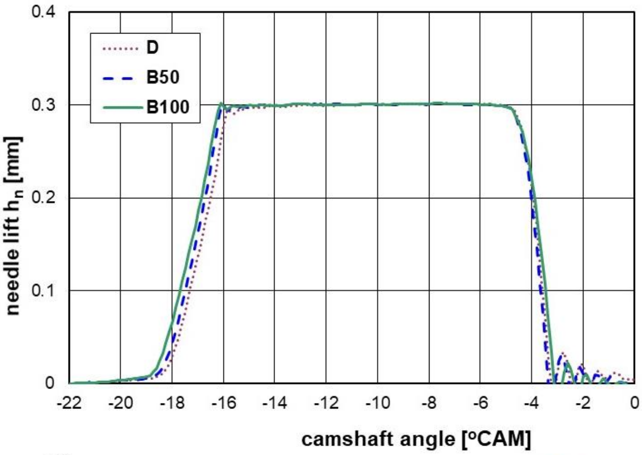


***Fig. 3** Fuel influence on pressure p_{II} [1]*

Biodiesel usage leads to advanced needle lift (Fig. 4) [1] and injection timing, especially in mechanically controlled injection systems.



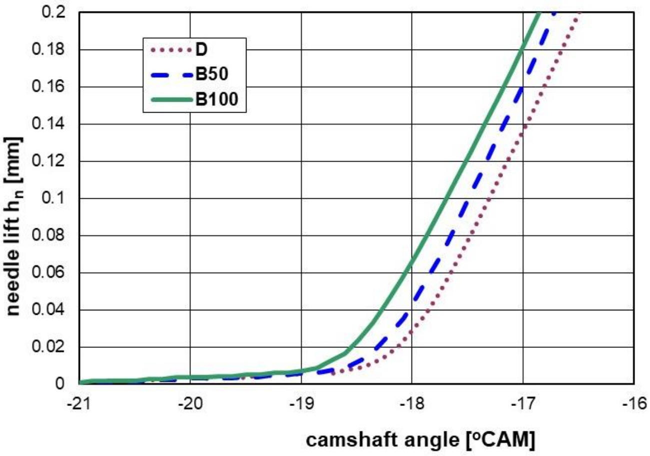


Fig. 4 *Fuel influence on needle lift h_n [1] (above) and segment from -21 to -17 °CAM (below)*

The advanced start of needle lift results in longer injection duration which raises the amount of injected biodiesel per cycle compared to diesel. The values for B50 are between the values for B100 and D.

4 CONCLUSION

Producing biodiesel from different raw materials and different technological biodiesel production processes can result in different standardized characteristics of biodiesel. This may also be the cause of the different values of the physico-chemical non-standardized biodiesel characteristics mentioned above (even though it satisfies the regulatory standards).

Researchers sometimes do not specify the origin and characteristics of biodiesel (or only some of the characteristics are shown) or used biodiesels with characteristics not according to the regulatory standards.

It is necessary to align the biodiesel (and mixtures) characteristics with the appropriate standards and that there is a stable source of biodiesel with constant properties.

From the aspect of using biodiesel as a diesel engine fuel and the effects on engine operation, it is important that processes that take place in the fuel supply systems, injection and mixture formation processes, as well as knowledge of biodiesel characteristics that are not prescribed by standards (speed of sound, bulk modulus, surface stress, etc.) are fully studied and clear.

Biodiesel obtained from algae occupies a very high position as a fuel for diesel engines according to its characteristics (Table 2), yet as a relatively new fuel, with a specific production technology, it is still much less produced and used compared with biodiesels made from rapeseed oil, soybean oil, oil palms, etc.

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PRODUCTION LOGISTICS AND OTHER ASPECTS OF TRANSPORT AND LOGISTICS

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PREDICTION OF MATERIAL DAMAGE ACCORDING TO THE HASHIN CRITERION WHEN A BULLET IMPACTS A COMPOSITE PLATE

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Abstract

In this paper, the finite element method was applied to test the resistance of the composite material in case of impact loading. The finite element method is a modern numerical method widely used to solve engineering problems. The method is implemented using Abaqus computational software. The simulation was performed for the case of a bullet impacting a composite plate. A 9 [mm] bullet with a given initial velocity and rotation hits the composite plate. The plate has three layers and is made of Kevlar 49. As it is an explicit dynamic analysis, the simulation is controlled by the VUMAT subroutine supported by the FORTRAN programming language. The evaluation was based on the Hashin criteria, defined in the subroutine. The objective is to perform an analysis of the composite plate and determine whether it was damaged by the impact. A possible application of the research is in ballistic vests, which is to determine whether the vest provides the user with reliable passive protection.

Key words*: finite element method (FEM), Hashin criteria, modeling, contact analysis, simulation, composite plate*

1 INTRODUCTION

Composite materials [1] are increasingly used as modern materials that provide light and strong structural properties. As their structure is multi-layered, there is a possibility of variation in the number, thickness and orientation of the layers, as well as the material of individual layers. This characteristic represents the suitability of the material in the form of adaptation to the necessary requirements. They are used in automotive, aviation, aerospace, aeronautical, defense and other industries where their application is possible. Knowing the limit values in the form of extreme properties of certain properties enables their correct application. In this paper, the composite plate was tested for impact load, based on works cited [2].
The simulation was realized in Abaqus software, using the finite element method (FEM). The picture of the stress and the results of the failure coefficients were used to predict plate damage. In this way, the state of the mechanical properties of the material of the composite plate was observed. There are several criteria according to which it is possible to make a prediction: Tsai-Hill, Azzi-Tsai-Hill, Hashin, Tsai-Wu. The Hashin Failure Criterion [3] was used in the paper. In the main program of the software, the subroutine VUMAT for the explicit, dynamic solver is implemented, where the laws of the material are applied. As part of the VUMAT subroutine, another subprogram was used, written on the basis of the Hashin criteria, which is intended for monitoring the values of the failure coefficients.

The visualization of the simulation results showed an image of the plate stress, and the subprogram provided the values of the Hashin coefficients. The analysis of the results served to evaluate the state of the proposed solution as well as to consider the possibility of improvement.

2 FAILURE CRITERIA

Failure criteria are commonly used in finite element analysis (FEA) to predict failure events in composite structures [4]. The most commonly used are strength-based failure criteria. They are:

- Maximum stress criterion,
- Maximum strain criterion,
- Truncated maximum strain criterion,
- Interacting failure criterion.

Failure criteria are presented using the notion of failure index and it is defined as:

$$I_F = \frac{stress}{strength} \quad (1)$$

Failure is predicted when $I_F \geq 1$. The strength ratio is the inverse of the failure index:

$$R = \frac{1}{I_F} = \frac{strength}{stress} \quad (2)$$

Failure is predicted when $R \leq 1$.

2.1. Hashin Failure Criterion

The Hashin Failure Criterion (HFC) proposes four separate modes of failure:

- Fiber tension,
- Fiber compression,
- Matrix tension,
- Matrix compression

that are predicted by four separate equations, as follows:

$$I_{Fft}^2 = \left(\frac{\sigma_1}{F_{1t}}\right)^2 + \alpha\left(\frac{\sigma_6}{F_6}\right)^2 \text{ if } \sigma_1 \geq 0 \quad (3)$$

$$I_{Ffc}^2 = \left(\frac{\sigma_1}{F_{1c}}\right)^2 \text{ if } \sigma_1 < 0 \quad (4)$$

$$I_{Fmt}^2 = \left(\frac{\sigma_2}{F_{2t}}\right)^2 + \left(\frac{\sigma_6}{F_6}\right)^2 \text{ if } \sigma_2 \geq 0 \quad (5)$$

$$I_{Fmc}^2 = \left(\frac{\sigma_2}{2F_4}\right)^2 + \left[\left(\frac{F_{2c}}{2F_4}\right)^2 - 1\right]\frac{\sigma_2}{F_{2c}} + \left(\frac{\sigma_6}{F_6}\right)^2 \text{ if } \sigma_2 < 0 \quad (6)$$

Where α is a weight factor to give more or less emphasis to the influence of shear on fiber failure.
In the above equations, based on works cited [5]:

- F_{1t} denotes the longitudinal tensile strength,
- F_{1c} denotes the longitudinal compressive strength,
- F_{2t} denotes the transverse tensile strength,
- F_{2c} denotes the transverse compressive strength,
- F_4 denotes the transverse shear strength,
- F_6 denotes the longitudinal shear strength,
- σ_1, σ_2, and σ_6 are components of the effective stress tensor, σ, that is used to evaluate the initation criteria and which is computed from:

$$\sigma = \boldsymbol{M\sigma} \quad (7)$$

where **σ** is the true stress and ***M*** is the demage operator:

$$M = \begin{bmatrix} \frac{1}{(1-d_f)} & 0 & 0 \\ 0 & \frac{1}{(1-d_m)} & 0 \\ 0 & 0 & \frac{1}{(1-d_s)} \end{bmatrix} \quad (8)$$

where d_f, d_m, and d_s are internal (demage) variables that characterize fiber, matrix, and shear damage, which are derived from damage variables d^t_f, d^c_f, d^t_m, and d^c_m, corresponding to the four modes previously discussed, as follows:

$$d_f = \begin{cases} d_f^t \text{ if } \sigma_1 \geq 0 \\ d_f^c \text{ if } \sigma_1 < 0 \end{cases} \quad (9)$$

$$d_m = \begin{cases} d_m^t \text{ if } \sigma_2 \geq 0 \\ d_m^c \text{ if } \sigma_2 < 0 \end{cases} \quad (10)$$

$$d_s = 1 - (1 - d_f^t)(1 - d_f^c)(1 - d_m^t)(1 - d_m^c) \quad (11)$$

3 FINITE ELEMENT MODELING

3.1. Creation of models

To create conditions for the simulation, the analysis object was modeled in Abaqus software. Since it is the contact analysis of the impact between two bodies, a 9 [mm] bullet grain model [6] and a three-layer composite plate model were created.
The grain of the bullet is modeled in an ellipsoidal shape using the technique of rotation around the y-axis, according to the dimensions in accordance with the technical description, where the semi-major axis is 10.5 [mm] and the minor semi-axis is 4.5 [mm], Figure 1. The center of mass, m = 8 [g], is located at the top of the bullet in the form of a reference point. The bullet is placed as a rigid body ("Discrete rigid"), without the possibility of deformation. It is discretized with finite elements of the type "R3D4 A 4-node linear quadrilateral elements" and "R3D3 A 3-node linear triangular elements", with a total of 2900 elements. The mesh is more finely divided near the top of the bullet, Figure 1.

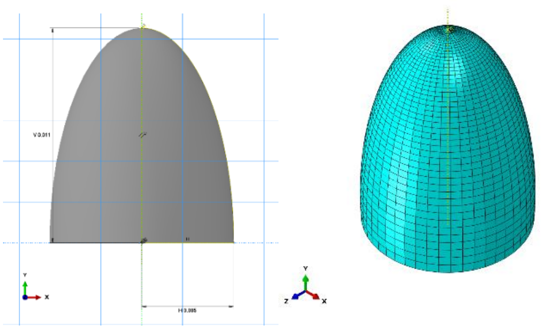

Fig. 1 *Contactor model, bullet grain 9 [mm].*

The plate is modeled in a three-dimensional square-shaped space with dimensions 100 x 100 [mm], Figure 2. The structure of the plate is in the form of a 3D deformable plate. It consists of three layers, which make up the total thickness of the plate of 9 [mm]. The orientation of the layers is as follows: [45/90/-45]. It is discretized with elements of the type "C3D8R A 8-node linear hexahedral elements". A total of 465660 elements were used. In the area where the highest stresses are expected, the discretization mesh is of a finer division.

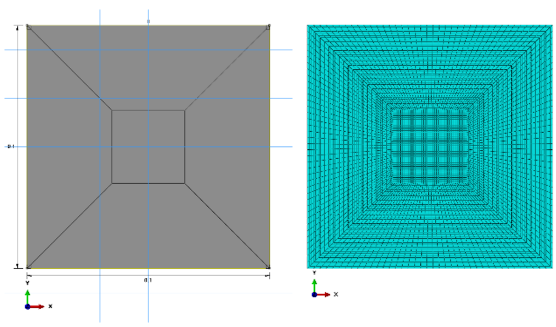

Fig. 2 *Target model, composite plate.*

3.2. Material

Based on the criterion that the material should be resistant to impact loads, a design for damage tolerance is recommended. As Kevlar fibers and tough matrices can provide the necessary impact and damage propagation resistance, the type of Kevlar 49 material was chosen. Kevlar composites have low density, high tensile strength, and excellent toughness and impact resistance. In accordance with the properties of the selected material, based on works cited [7], density ρ, modulus of elasticity E_1, E_2, E_3, and shear modulus G_1, G_2, G_3 in the longitudinal and transverse directions, and Poisson's coefficients υ_{12}, υ_{23}, υ_{13} were defined, with the values shown in Table 1. Also, the strength coefficients are defined as follows: tensile strengths F_{1t}, F_{2t}, F_{3t}, compressive strengths F_{1c}, F_{2c}, F_{3c} along the principal ply direction, and shear strengths F_4, F_5, and F_6, as shown in Table 1.

Table 1 Properties of Kevlar 49 material

Properties	Value
Density, ρ	1380 [kg/m^3]
Longitudinal modulus, E_1	80 [GPa]
Transverse in-plane modulus, E_2	5.5 [GPa]
Transverse out-of-plane modulus, E_3	5.5 [GPa]
In-plane shear modulus, G_1	2.2 [GPa]
Out-of-plane shear modulus, G_2	1.8 [GPa]
Out-of-plane shear modulus, G_3	2.2 [GPa]
Major in-plane Poisson's ratio, υ_{12}	0.34
Out-of-plane Poisson's ratio, υ_{23}	0.40
Out-of-plane Poisson's ratio, υ_{13}	0.34
Longitudinal tensile strength, F_{1t}	1400 [MPa]
Transverse tensile strength, F_{2t}	30 [MPa]
Out-of-plane tensile strength, F_{3t}	30 [MPa]
Longitudinal compressive strength, F_{1c}	335 [MPa]
Transverse compressive strength, F_{2c}	158 [MPa]
Out-of-plane compressive strength, F_{3c}	158 [MPa]
Out-of-plane shear strength, F_4	[MPa]
Out-of-plane shear strength, F_5	37 [MPa]
In-plane shear strength, F_6	49 [MPa]
Damping parameter	10^{-9}

3.3. Initial conditions

Initial conditions determine the movement of the bullet and how the plate is supported. The bullet is defined to move in a straight line along the negative z-direction V_3 = -100 [m/s] with the effect of rotation around the z-axis counter-clockwise VR_3 = 3500 [rad/s]. The plate is supported at all ends (U_1=U_2=U_3=UR_1=UR_2=UR_3=0), as shown in Figure 3. The bullet hits the central part of the plate at a right angle producing a load. As the load on the plate is greatest when the bullet strikes at an angle of 90 degrees, the worst possible scenario is observed.

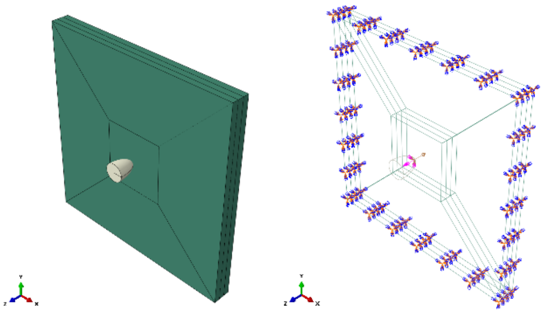

Fig. 3 *Initial position and constraint conditions.*

4 SIMULATION

The simulation was realized in Abaqus software based on previously prepared models and defined initial conditions. It is a nonlinear contact analysis in which the contactor is the grain of the bullet and the target is a composite plate. Since the impact is instantaneous, the explicit dynamic solver of the mentioned software was used. The duration of the simulation is $t = 5 \cdot 10^{-5}$ [s] and it was realized in 89273 integration steps. The correct choice of duration and a sufficient number of steps was a necessary condition for the stability of the simulation. Since the software supports the possibility of implementing subprograms, an algorithm was written to control the flow of the simulation. The main software program is called the VUMAT subroutine, written in the FORTRAN programming language [8], according to instructions in works cited [9]. The subroutine code is used to solve the problem. The algorithm flow is the following: reading material properties according to Table 1, calculating the stiffness matrix, updating the total strains and stresses at each integration step, failure evaluation, and integrating the internal specific energy. In the damage monitoring part, another subprogram is called within the VUMAT subroutine, which is written according to the material laws of the Hashin criteria.

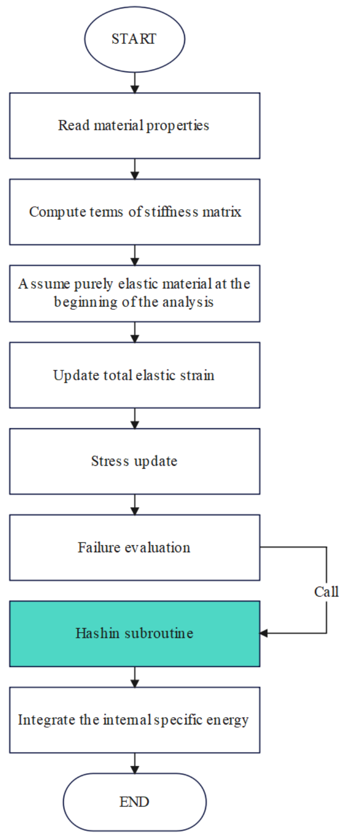

Fig. 4 *Algorithm, VUMAT subroutine.*

Hashin's subprogram uses two *"If"* conditions of inequality in the form of normal stresses σ_1, σ_2, which control the further course of determining the coefficients of failure, according to the algorithm shown in Figure 5. Stress σ_1 determines the coefficient of fiber tension or compression (equations 3 and 4), while σ_2 determines the coefficient of matrix tension or compression (equations 5 and 6). If condition $\sigma_1 \geq 0$ is satisfied, equation (3) is applied, otherwise equation (4) is applied. If condition $\sigma_2 \geq 0$ is satisfied, equation (5) is applied, otherwise equation (6) is valid. Equations (3) to (6) are used to calculate the failure index I_F, or the strength ratio R, equation (2). If they satisfy the condition that the failure index $I_F \geq 1$, that is the strength ratio $R \leq 1$, the plate is predicted to be damaged.

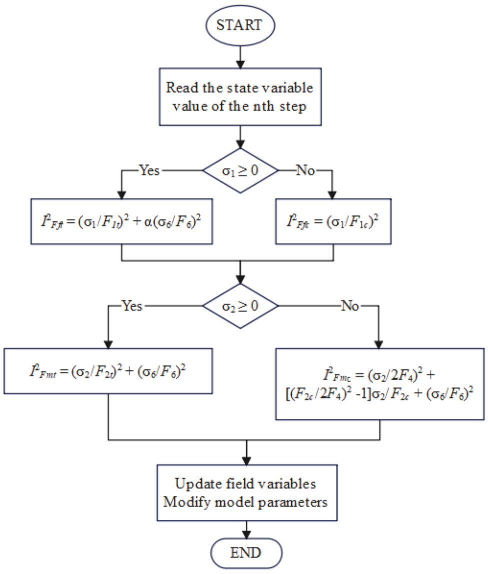

Fig. 5 *Hashin subroutine.*

5 RESULTS AND DISCUSSION

The results of the simulation are shown in 100 images and enable the monitoring of the stress distribution during the realization. The bullet impacts the plate with a certain velocity and rotation. The maximum stresses increase according to the transfer of energy from the bullet to the plate. The visualization of the results showed that the specified stresses were sufficient to cause damage to the plate in the form of a crack. A sufficient number of integration steps allowed the monitoring of the crack formation in the impact zone, Figure 6. The installation of a three-layer composite plate, with the correct choice of materials and orientation of the layers, prevented the crack from spreading above the impact zone, as well as the failure of the complete plate.

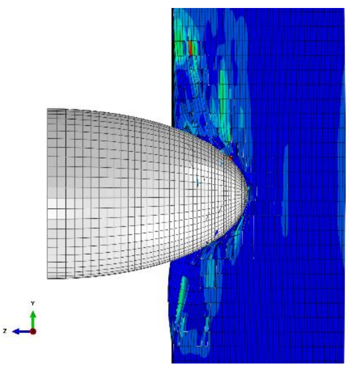

Fig. 6 *Display of plate cracks in the y-z plane.*

The final values of the monitored variables were recorded as relevant. In Figure 7, the Von Mises stress is shown as S (σ=1.292·10^9 [Pa]). Figures 8 and 9 show the normal stresses S_{11} (σ_1=1.301·10^9 [Pa]) and S_{22} (σ_2=2.088·10^7 [Pa]).

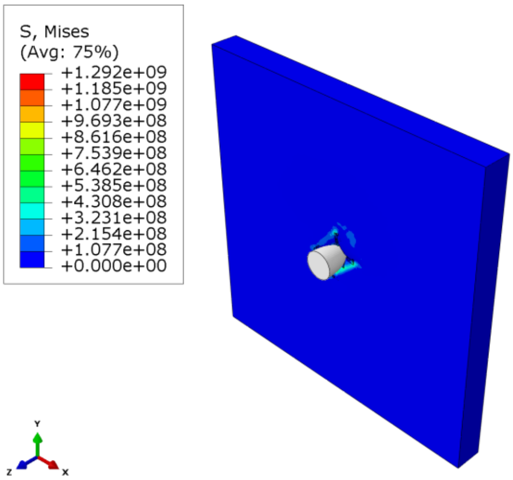

Fig. 7 *Von Mises Stress, σ.*

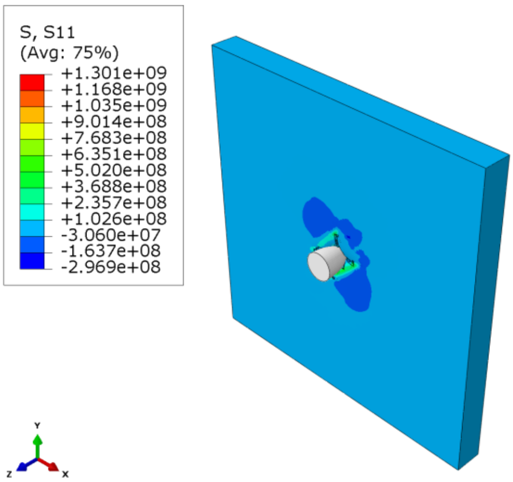

Fig. 8 *Normal Stress S_{11}, σ_1.*

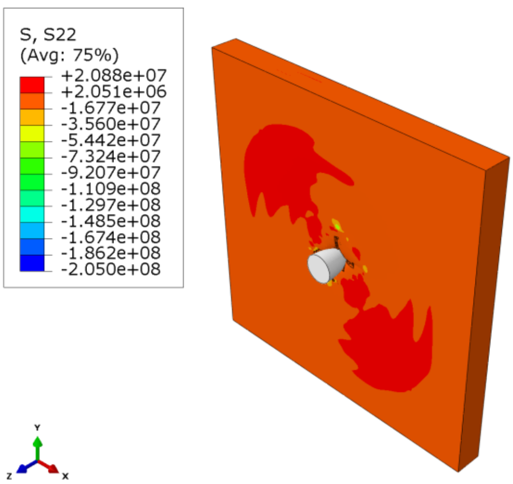

Fig. 9 *Normal Stress S_{22}, σ_2.*

During the realization of the simulation, the failure coefficients were simultaneously recorded in a separate (*txt*) file. The coefficients are presented in the form of a graph, where the x-axis indicates the number of data, while the value of the coefficient is given on the y-axis, Figure 9.

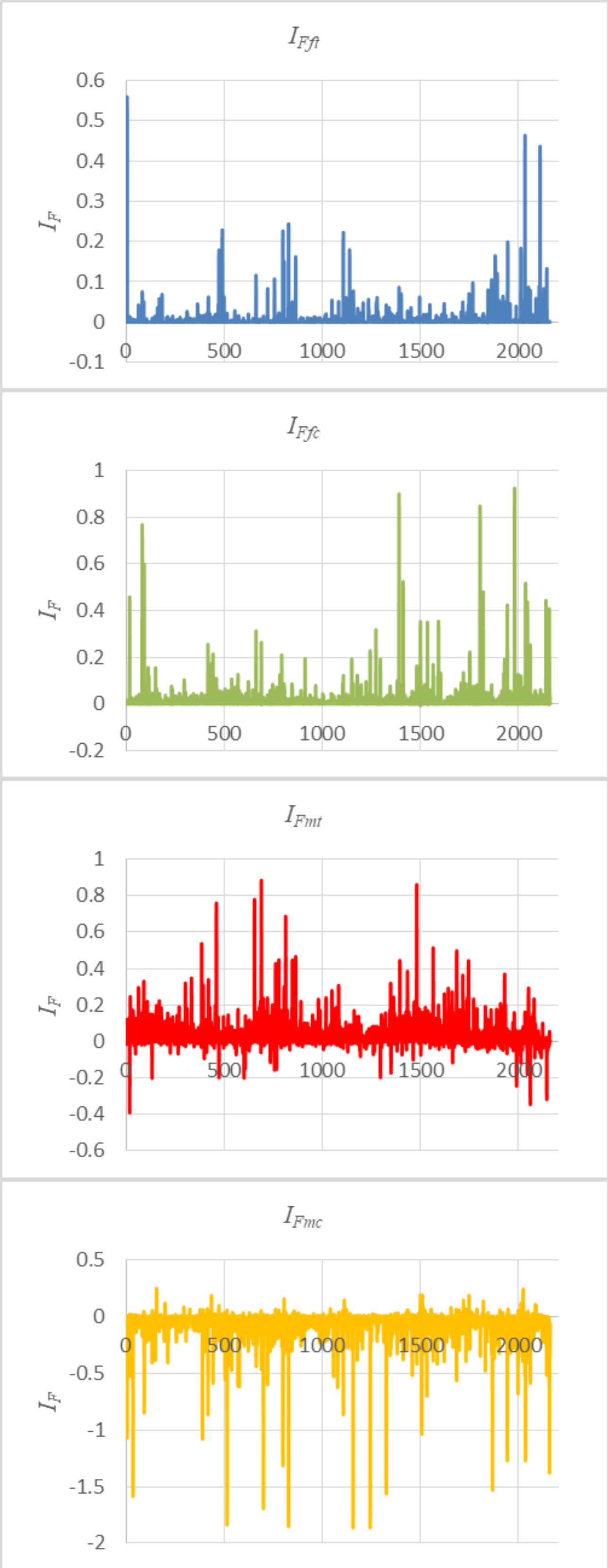

Fig. 9 *The failure coefficients.*

From the analysis of the graphs of all coefficients, it can be concluded that the compression matrix coefficient I_{Fmc} has the greatest influence, since it satisfies the condition of being greater than one $I_F \geq 1$, according to the given criteria. The results of the failure index agreed with the simulation results for stress. In this way, the correctness of the setting and implementation of the simulation in a customized software according to the given problem was confirmed.

6 CONCLUSION

The analysis was done for the realistic problem of a bullet impacting a composite plate. The models of the bullet and the plate were created directly using the mesh modeler in the Abaqus software. A software option was used to implement a subroutine written in the FORTRAN programming language. The VUMAT subroutine was implemented in the main software program, influencing the course of the simulation, which used the finite element method. Hashin's subroutine allowed tracking the values of the failure coefficients, which the software couldn't do, according to the given simulation setting. This achieved the effect of aligning the software to the specific problem and thus improved its capabilities. Hashin's criterion was shown to be successful in predicting damage caused by impact loading, as the simulation stress picture coincided with the previous statement. Considering that the plate didn't break, it can be concluded that this plate set meets the requirements for user safety. Further research will be reflected in experimental verification, which requires special conditions.

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SOLVING SINGLE TOOL HOLE DRILLING PATH OPTIMIZATION PROBLEMS USING EVOLUTIONARY ALGORITHM

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Abstract

Given the high prevalence of the hole drilling process in manufacturing, its optimization, from the aspects of achieving cost savings and productivity improvement, is of utmost importance. Therefore, in the present research three single tool hole drilling optimization problems with different number of holes and hole patterns were defined in CAM software. In order to investigate whether there exist better hole drilling sequences with shorter drill travel paths, the drill travel path was formulated as a travelling salesman problem (TSP) and solved using evolutionary algorithm (EA). The optimization results show that EA is able to provide better hole drilling sequences, and thus achieve considerable savings in terms of the total drill travel distance, which indicates the expediency of its application.

Keywords*: drilling, TSP, drill travel path, evolutionary algorithm, CAM software.*

1 INTRODUCTION

Drilling is one of the most common machining processes standardly used for producing holes on conventional drilling machines, lathes, boring mills, and milling machines [1]. Most often, it is a preliminary, rough machining operation, which creates cylindrical openings and holes in different kinds of materials with a tool called a drill. The machining principle is based on the main rotary movement of the drill which at the same time performs an auxiliary rectilinear movement into the workpiece material [2]. For a given drilling operation, process performance is affected by the workpiece material, drill material and geometry, process cooling/lubrication conditions as well as drilling process parameters such as feed rate and spindle speed.

Given that this machining technology is omnipresent in many industries [3], the efforts in the direction of drilling process optimization are always current. Generally, as in the case of other machining technologies, improvement of the most important performances, related to costs, productivity and quality characteristics, can be achieved by drilling parameter optimization, development of better machine tools and drills and also optimization of drill path for the given case study. From the aspect of required financial resources, and also the possibility of increasing the efficiency of using the existing machining systems, optimization of drilling parameters and drill paths is much more receptive. Given that non-cutting time in drilling can take up to 70% of the total time [4], determining of optimal drill paths can result in significant savings, particularly in mass production [5].

Nearest neighbor algorithm is commonly used for solving tool route planning problems in CNC machining, but although the algorithm is simple to implement it does not guarantee optimal path [6]. Considering this fact and the actuality of the topic, many authors have dealt with optimization of drill path using different methods and approaches including tabu search algorithm [7], genetic algorithms (GA) [8-10], particle swarm optimization (PSO) [11, 12], ant colony optimization (ACO) [13-15], bees algorithm [16], bat algorithm [17], modified shuffled frog leaping algorithm (MSFLA) [18], ant algorithm [19], magnetic optimization algorithm [20], gravitational search algorithm [6], teacher-learner-based optimization (TLBO) algorithm [21], biogeography based optimization (BBO) algorithm [22], 2-opt heuristic evolutionary algorithm [23], adaptive-dhouib-matrix-3 (A-DM3) [24], Lin–Kernighan heuristic [25], etc. In order to search for possible better solutions, hybrid algorithms were also proposed, such as hybrid cuckoo search-genetic algorithm (CSGA) [26] and SFLA-ACO [27]. Some of the reviewed studies had previously defined geometrical models for a particular case study, while the others attempt to solve different drill path benchmark optimization problems using different algorithms and comparing their effectiveness and suitability. In the implementation of the aforementioned algorithms and approaches for solving drill path optimization problems different goals were defined, such as minimization of drill airtime and switch time, total drill travel distance, drilling costs, machining time etc., which otherwise are intended to enhance effectiveness of drilling process with the ultimate aims of reducing costs and increasing productivity.

Review of optimization studies between 1995 and 2017 in drilling path optimization is performed by Abidin et al. [28]. A more recent and comprehensive review of the same topic, but with more useful insights, related to the classification of the drilling problems, modeling approaches, optimization algorithms and proposed objective functions, was given by Dewil et al. [29]. According to the proposed classification, a distinction can be made between single tool drilling, multi-tool drilling, multi-tool drilling with precedence constraints and multi-tool hole drilling with sequence dependent drilling times.

With the application of the CAD/CAM systems productivity of machine tools has been substantially increased [8, 15]. Moreover, automatic generation of the G-code is much easier and less time consuming compared to manual programming, however, the generated tool paths are not guaranteed to be optimal [6, 8, 13] and many research studies are focused on solving this issue. Having in mind the aforementioned, in the present study an attempt has been made to apply evolutionary algorithm (EA) to determine the optimal drill path and shortest travel distance in drilling of steel plates with solid carbide drill. In addition, the results of EA were compared with the results of commercial software such as FeatureCAM. For the purpose of analyzing the possibilities of applying EA and comparison of the obtained results with FeatureCAM, three single tool hole drilling case studies, with 15, 18 and 22 holes of the same diameter, were defined.

2 CASE STUDIES

General single tool drilling path optimization problems were considered in the present research. The goal was to determine hole drilling sequences to minimize the drill path lengths while starting and finishing in the origin of the coordinate system.

Hole drilling operation at 15 positions (case study 1) is considered as a reference case to investigate the discussed approach (Figure 1a). Stock is a block with the width of 115 mm, the length of 140 mm and the thickness of 25 mm made of steel. The machine tool is the CNC vertical milling machine. The cutting tool is a solid carbide drill with the diameter of 6 mm. Drilling depth is 15 mm for all holes. Hole drilling operation at 15 positions was simulated in FeatureCAM Ultimate 2022 software. Operations were ordered automatically in FeatureCAM software using the "Minimize rapid distance" option. This option changes the order of specified features (drilling operations at specified positions). Case study 2 considers the same machine tool, cutting tool and hole dimensions, but with different stock dimensions, hole pattern and the number of holes which is 18 (Figure 1b). Finally, case study 3 considers the more complex drill path optimization problem. The same machine tool, cutting tool and hole dimensions are considered, but with different stock dimensions, hole pattern and the number of holes which is now 22 (Figure 1c).

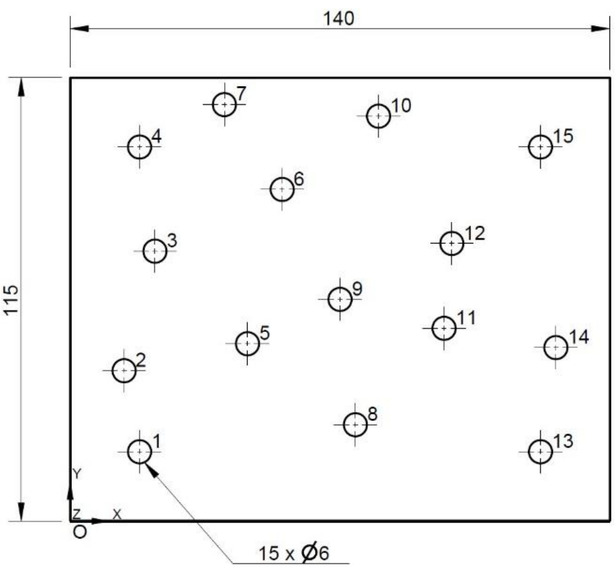

Fig. 1a *Technical drawings of the finished part: a) case study 1*

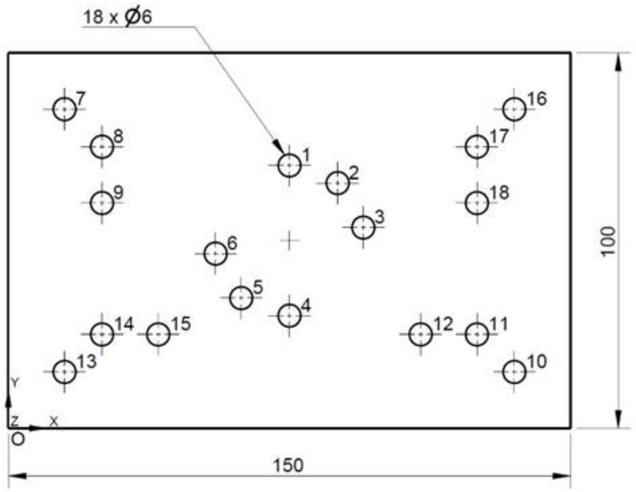

Fig. 1b *Technical drawings of the finished part: a) case study 2*

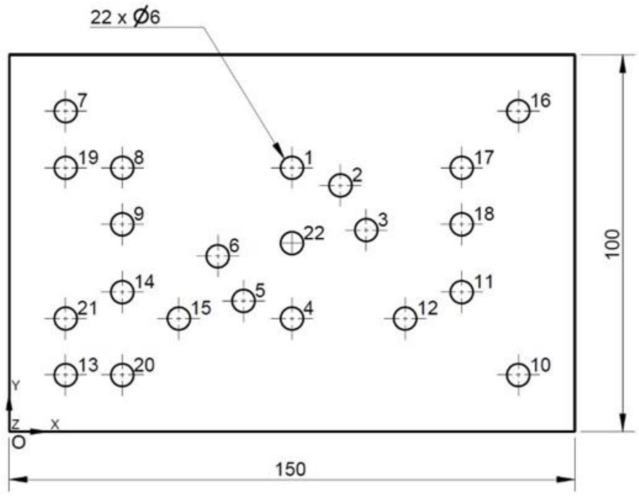

Fig. 1c *Technical drawings of the finished part: a) case study 3*

3 PROBLEM FORMULATION AND APPLIED OPTIMIZATION APPROACH

Determination of the optimal drill path sequence is an important problem in CNC drilling [17]. A single tool drilling path optimization problem can be modelled as a travelling salesman problem (TSP) [12, 29]. The TSP is a well-known combinatorial optimization problem from the category of NP-hard problems that cannot be solved exactly in polynomial time. Branch-and-bound algorithms and cutting plane method are commonly used exact algorithms to find solutions for TSPs [30]. Given that the TSP is an NP-hard problem, heuristic algorithms are commonly used to obtain approximate solutions, but not necessarily optimal. Among these, tour construction heuristic algorithms (nearest neighbor, greedy, insertion algorithms, Christofide heuristic) and tour improvement heuristic algorithms (2-opt and 3-opt, k-opt, Lin-Kernighan algorithm, TS, SA etc.) are widely used. The basic goal of the problem is to find the shortest possible path through a set of interconnected nodes so that each node is visited only once. TSP plays a significant role in the theory of algorithms, serving as a challenging problem for the development and improvement of existing optimization algorithms. A single tool drilling path optimization problem can be modeled as TSP with the following mathematical formulation [24, 29]:

$$\begin{aligned} & Min \sum_{i=1}^{n} \sum_{j=1, i\neq j}^{n} c_{ij} x_{ij} \\ & \sum_{j=1, j\neq i}^{n} x_{ij} = 1, \quad i = 1, \ldots, n \\ & \sum_{i=1, i\neq j}^{n} x_{ij} = 1, \quad j = 1, \ldots, n \\ & x_{ij} = 0, i = 1, \ldots, n, j = 1, \ldots, n \end{aligned} \qquad (1)$$

where x_{ij} is the binary decision variable and c_{ij} is the distance from hole i to hole j. While solving presented case studies the Euclidean distance was employed to calculate the distance between the hole positions. Due to exponential increase in the number of possible drill path sequencies when the number of holes increases, application of various evolutionary algorithms is justified for solving this type of optimization problem [17]. Therefore, in the present study nondeterministic, gradient free evolutionary algorithm (EA) was adopted. Although the performance of each metaheuristic algorithm is dependent of tuning of specific hyper-parameters, constant parameter set of the EA was used during optimization (population size of 100, mutation rate of 0.75 and a random seed of 0), taking into account not so great complexity of considered problems as well as the fact that the study does not primarily analyze performance of the EA itself.

4 APPROACH RESULTS AND DISCUSSION

In this section the optimal drill paths and shortest travel distances, determined by the EA, were compared with the results obtained using FeatureCAM commercial software. Toolpaths simulation in FeatureCAM Ultimate 2022 showing recommended drill path and visual representation of the best drill path determined with the application of the EA are given in Figure 2. As could be observed from Figure 2a, for the case study 1, FeatureCAM recommended drill path implies the following sequence of hole drilling: 1-2-3-4-7-6-10-12-11-9-5-8-13-14-15. On the other hand, the best sequence obtained with the application of EA is somewhat different: 1-2-3-4-7-6-10-15-12-9-5-8-11-14-13.

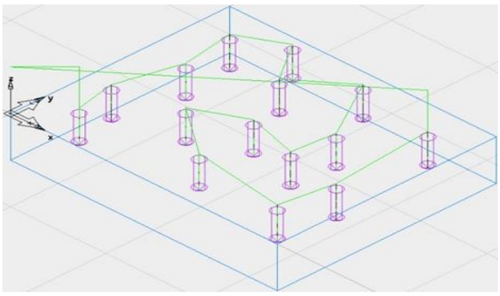

Fig. 2a. *Drill paths for case study 1 determined by the application of FeatureCAM (toolpath simulation)*

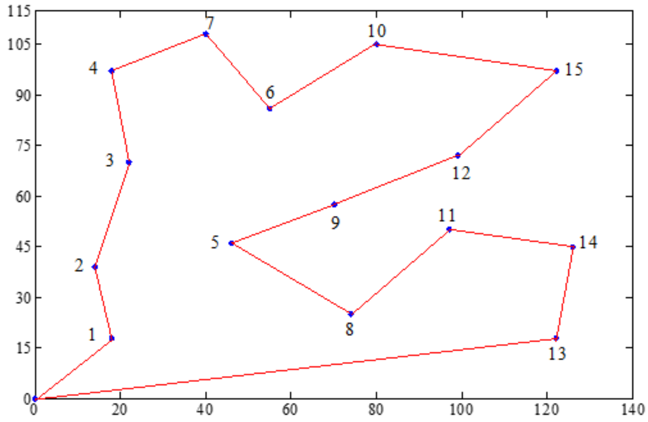

Fig 2b. *Drill paths for case study 1 determined by EA*

Drill paths with hole drilling sequences for the second case study are given in Figure 3. As could be observed from Figure 3a, for the case study 2, FeatureCAM recommended drill path implies the following sequence of hole drilling: 7-8-9-6-5-4-3-2-1-17-16-18-11-10-12-15-14-13. On the other hand, the best sequence obtained with the application of EA significantly differs: 13-14-15-4-5-6-9-8-7-1-2-3-12-11-10-18-17-16.

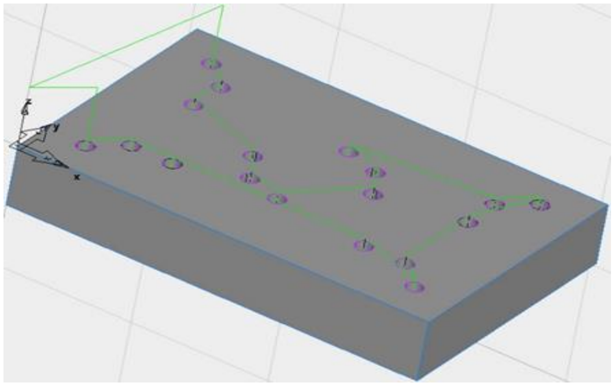

Fig 3a. *Drill paths for case study 2 determined by the application of FeatureCAM (toolpath simulation)*

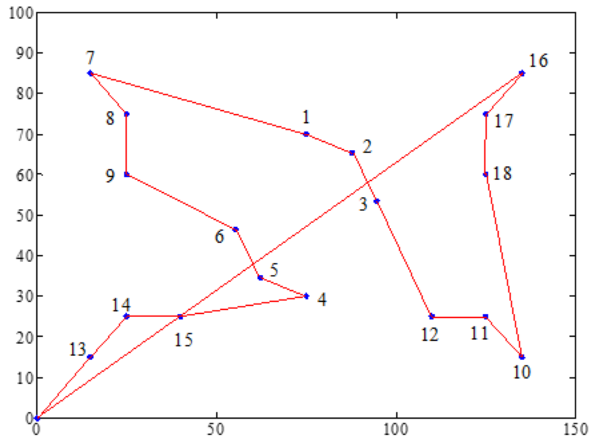

Fig 3b. *Drill paths for case study 2 determined by EA*

Drill paths with hole drilling sequences for the third case study are given in Figure 4. As could be observed from Figure 4a, for the case study 3, FeatureCAM recommended drill path implies the following sequence of hole drilling: 7-19-8-9-14-21-13-20-15-5-4-22-1-2-3-18-17-16-11-12-10-6.

On the other hand, the best sequence obtained with the application of EA significantly differs: 21-14-9-19-7-8-6-22-1-2-3-17-16-18-11-10-12-4-5-15-20-13.

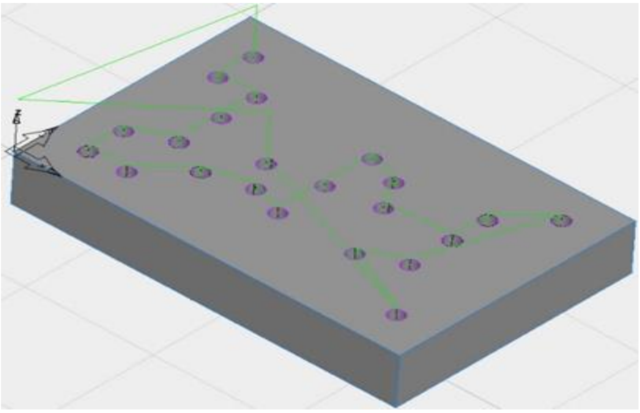

Fig 4a. *Drill paths for case study 3 determined by the application of FeatureCAM (toolpath simulation)*

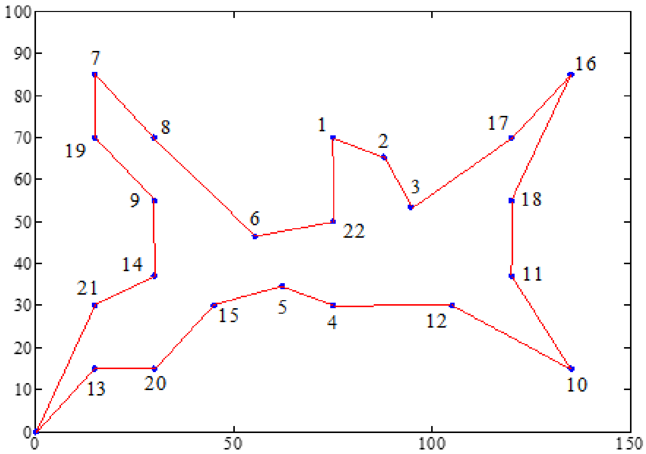

Fig 4b. *Drill paths for case study 3 determined by EA*

The comparison of resulting total drill path length for each case study, as determined by the EA and based on FeatureCAM recommended hole drilling sequence, is given in Table 1.

Table 1 Comparison of drill path lengths for determined hole drilling sequences

Case study	Number of holes	Drill path length (mm)	
		FeatureCAM	EA
1	15	466.53	450.22
2	18	500.52	401.3
3	22	635.82	509.42

As could be observed from Table 1, solving drill path optimization problems with EA results in better solutions, i.e., determination of hole drilling sequences with shorter drill path lengths. This is pronounced in case studies 2 and 3 where the number of holes to be drilled is increased. Even more significant differences in results between GA and different CAM software (WinCAM, CAMConcept and CATIA V5) were previously observed by Pezer [9] on the example of drilling of 158 holes in the prismatic workpiece.

5 CONCLUSION

Solving drill path optimization problems is very important in CNC machining and represents one of the ways to optimize the hole drilling process with respect to time or costs. In this paper, three single tool hole drilling case studies, with 15, 18 and 22 holes of the same diameter, were developed, modelled as a TSP problem, solved with EA and the obtained results were compared with the results from FeatureCAM. Based on the obtained results the following conclusion can be drawn:

- Although different CAM software have built in optimization modules and procedures for generation of tool paths, the applied EA proved to be able to determine a more favorable hole drilling sequences, having shorter drill path lengths, closer to the global optimum.
- The difference in total drill path lengths between results of FeatureCAM and EA is increased with the number of holes to be drilled and on average for all considered case studies is around 14%.
- While solving drill path optimization problem fast converge of the EA was observed with computational time of about 45s, without significant differences for three case studies.
- Process planning of complex drilling problems from industry should consider application of different optimization algorithms in an attempt to achieve additional cost and time savings.

In further research, the three developed case studies could be solved using other metaheuristic algorithms and their combination. Besides, analysis of algorithm specific parameter tuning, particularly in the case of more complex problems, might be a very interesting topic.

ACKNOWLEDGMENT

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STOCHASTIC SIMULATION MODEL FOR THE ANALYSIS OF ASSIST GAS COSTS IN CO_2 LASER OXYGEN CUTTING

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Abstract

Analysis of different technological and qualitative criteria as well as cost analysis in laser cutting is very important for evaluation of alternative cutting conditions. In this paper, a stochastic simulation model for the analysis of assist gas costs in CO_2 laser oxygen cutting was developed. For the definition of model and its parameters empirical model for estimation of assist gas consumption and industrial recommended interval values for main laser cutting parameters were considered, wherein normal distribution is set for the input parameters. After performing multiple simulation runs it was possible to construct a frequency distribution and estimate mean and variance descriptive statistics of assist gas costs for different sheet thicknesses. Another goal of the present study was to perform sensitivity analysis so as to analyze the effects of variation of input parameters on resulting change in assist gas costs for different sheet thicknesses.

Keywords: *Stochastic simulation model, CO_2 laser cutting, assist gas costs, mild steel.*

1 INTRODUCTION

As one of the leading non-conventional methods, technology of laser cutting has gradually replaced traditional technologies for contour cutting due to its high productivity, good quality and flexible processing capability [1]. Several other advantages and possibilities such as non-contact nature of the process, high precision and accuracy on complex features and possibility to cut a wide spectrum of materials [2], make this technology increasingly applicable in modern industries. Apart from numerous techno-technological and qualitative advantages, laser cutting is often considered as an economically viable technology for contour cutting of different materials in modern industry [3]. In practice, economic profitability, in terms of the possibility of realizing a certain profit and minimizing all necessary additional costs and waste, is of a variable nature and depends to a greater or lesser extent on numerous factors such as: material type and sheet thickness, selected laser cutting method (oxygen, fusion, sublimation), laser cutting technology, laser cutting machine running costs, labor costs, maintenance costs, sheet material utilization, production batch, specified quality characteristics, etc. Moreover, even all previous factors are taken as constants, selection of laser cutting parameter values, which govern interaction of laser beam and workpiece material as well as melt ejection from the kerf, may have decisive effect on the resulting costs of cutting. Considering that in many companies laser cutting regimes are determined with respect to recommendations from machine tool manufacturers, prior engineering experience, industrial practice guidelines, the question arises as to how much there is a difference in laser cutting costs given that laser cutting parameter recommendations usually consider interval data for different parameters such as laser power, cutting speed, nozzle diameter, assist gas pressure, focus position, etc. Overall CO_2 laser cutting costs comprises of fixed costs (investment, maintenance, labor, laser mix gases costs) and variable costs (electrical power and assist gas costs) [4]. In literature, limited number of studies has been performed with the focus on the analysis of laser cutting costs. Some analytical mathematical models for cost analysis in laser cutting are proposed in previous studies [3-7].
Given that factors that figure in fixed costs may vary significantly from country to country and from company to company, and that assist gas costs have highest share in variable costs, this paper analyzes the assist gas costs in CO2 laser oxygen cutting of mild steel with different sheet thicknesses. To this aim stochastic simulation model was developed for estimation of assist gas costs depending on the nozzle diameter and assist gas pressure. After performing 1000 simulation runs it was possible to construct a frequency distribution and estimate mean and variance descriptive statistics of assist gas costs for different sheet thicknesses. With the set constant assist gas price and recommended cutting speed values, it was possible to estimate assist gas costs per hour and per cut length for various thicknesses.

2 STOCHASTIC SIMULATION MODEL FOR ESTIMATION OF ASSIST GAS COSTS

Assist gas costs can be estimated as the product of assist gas consumption and assist gas price. The price of the assist gas on the Serbian market is variable and dependents upon the ordered quantity, purity level, as assist gas supplier and other factors. For smaller quantities the price for oxygen 3.5, provided by one of the leading suppliers of industrial gases, is approximately 3.07 EUR/m^3 [8]. Assist gas consumption is dependent on assist gas type and pressure and nozzle diameter. Many CNC laser cutting machine manufacturers provide tabular data and diagrams for the estimation of assist gas consumption. Based on the data provided by Bystronic laser cutting machine manufacturer, one can derive the following model estimation of the assist gas consumption for laser oxygen cutting of mild steel [4]:

$$Q_{ag} = 4.554 - 5.775 d_n - 1.513 p + 2.036 d_n^2$$

$$+0.046p^2 + 1.725 d_n p \quad (1)$$

where Q_{ag} (m^3/h) is the consumption of the assist gas, dn (mm) is the nozzle diameter and p (bar) is the assist gas pressure.

It is evident from Eq. (1) that assist gas consumption, and consequently assist gas costs, will vary depending on the selected nozzle diameters and set assist gas pressure for the particular cutting application. In general, the selection of particular laser cutting regime for a given sheet thickness and requirements is mainly guided by CNC laser cutting machine manufacturers recommendations, general industrial practice, as well as operators past experience and knowledge [8]. Given that reference guidelines for the most important parameters, for a particular laser cutting regime, may suggest variable range of values it is evident that selection of particular values may have decisive influence on assist gas costs. Therefore, the idea of the present study is to propose the following stochastic simulation model for the analysis of the assist gas costs in CO_2 laser oxygen cutting C_{ag} (EUR/h) in the following form:

$$C_{ag} = 3.07 \cdot (4.554 - 5.775 d_n - 1.513 p + 2.036 \cdot d_n^2 + 0.046 \cdot p^2 + 1.725 \cdot p \cdot d_n) \quad (2)$$

where p and d_n are assumed to be random variables which follow normal distribution, wherein mean and standard deviation values for different sheet thickness were determined based on industrial CO_2 laser cutting parameter recommendation guidelines [9]. For each sheet thickness 1000 simulation runs were performed so as to ensure accurate estimates of output variable (assist gas costs) distribution.

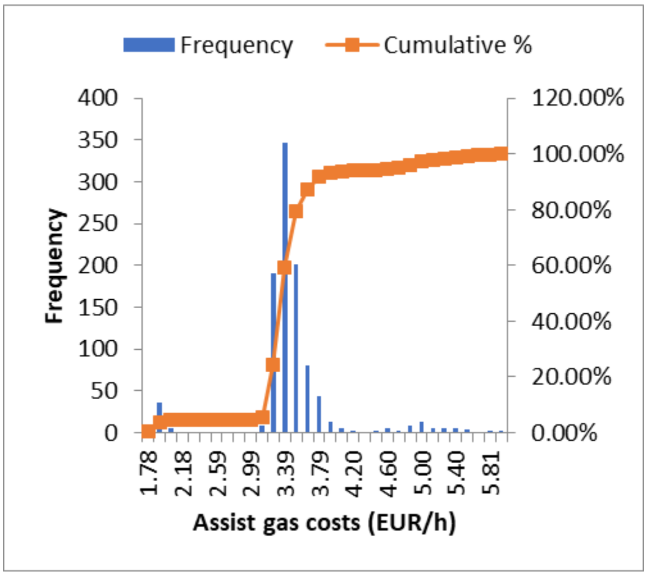
3 RESULTS AND DISCUSSION

Samples obtained by the stochastic simulation model for different sheet thicknesses are given by histograms and descriptive statistics so as to facilitate interpretation and analysis of assist gas costs data (Figure 1).

As could be observed from Figure 1(a) sample mean of assist gas costs equals 3.42 EUR/h. It is a measure of central tendency and actually represents the expected value of assist gas costs if the distribution of laser cutting parameters were random. The variability or scatter in the data may be described by the sample variance, the standard deviation and sample range. The standard deviation has the desirable property of measuring variability in the original units of the variable of interest [10]. The higher the standard deviation, the greater the variation (spread) from the mean assist gas costs. In the present case standard deviation equals 0.56 EUR/h while range is 4.16 EUR/h. Skewness and kurtosis are numerical measures of the shape of data. All data distributions are somewhat positively skewed (right skewed) indicating a greater number of smaller values. A large kurtosis value (sharp peak in the center and a lot of data in the tails) can be observed only for sheet thickness of d=1 mm and is associated with higher risk/opportunity because it indicates high probabilities of extremely large and extremely small assist gas costs.

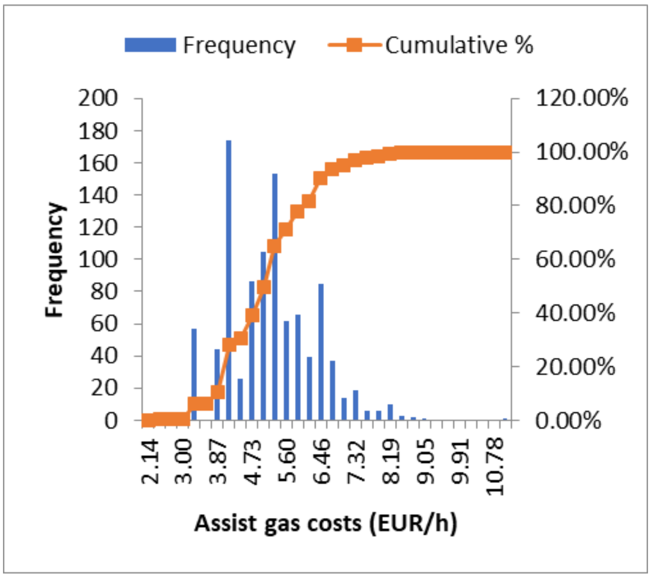
Based on data from Figure 1 one can obtain an estimate of assist gas costs per month. For example, if one considers 22 working days per month, 2 shifts per day with 8 working hours, 15% laser non-productive time and typical sheet thickness of 4mm, an estimate of 1430 EUR for average assist gas costs can be obtained. Minimal assist gas costs equal 627 EUR while maximal 2659 EUR. Eltawahni et al. [] reported that a significant reduction of about 71% in the overall cutting operating costs can be achieved if the economical setting is considered in CO_2 laser cutting of AISI 316L stainless steel.

Based on obtained data, one can confirm that this is actually the greatest difference between possible minimal and maximal costs, wherein these differences are more pronounced up to sheet thicknesses of 6 mm in comparison to sheet thicknesses between 8 and 18 mm. This can be explained by the fact that narrower process windows are being recommended for laser cutting of thicker steel sheets.



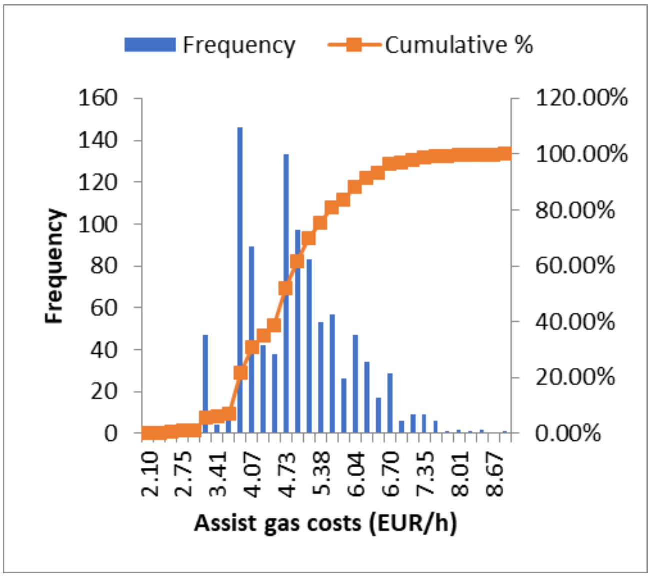
Mean	3.419
Standard Error	0.017578
Median	3.384921
Mode	3.384921
Standard Deviation	0.555877
Sample Variance	0.308999
Kurtosis	6.111909
Skewness	0.730285
Range	4.158622
Minimum	1.781214
Maximum	5.939836
Sum	3419
Count	1000

a) sheet thickness d=1 mm



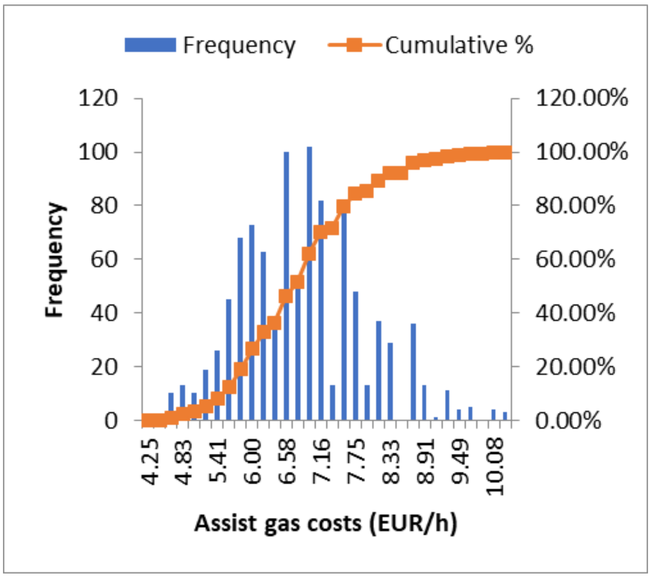
Mean	5.045354
Standard Error	0.035559
Median	5.025437
Mode	5.025437
Standard Deviation	1.124481
Sample Variance	1.264457
Kurtosis	0.750548
Skewness	0.512885
Range	8.923784
Minimum	2.140772
Maximum	11.06456
Sum	5045.354
Count	1000

b) sheet thickness *d*=2 mm



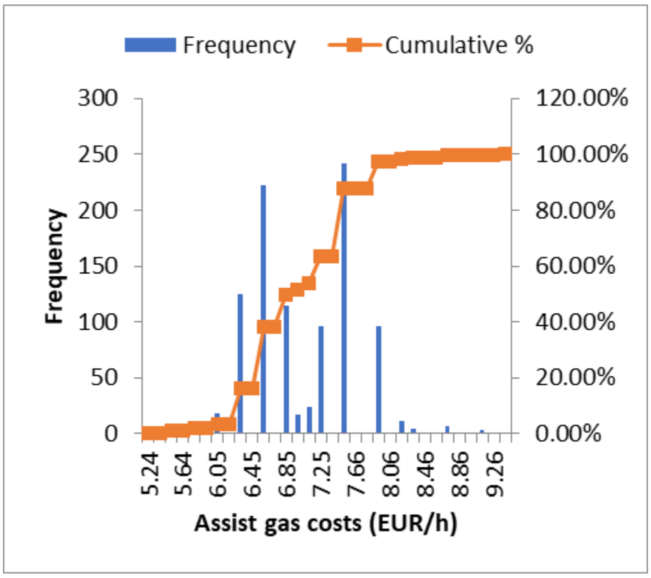
Mean	4.779256
Standard Error	0.032421
Median	4.722151
Mode	4.626705
Standard Deviation	1.02524
Sample Variance	1.051116
Kurtosis	0.325073
Skewness	0.515979
Range	6.790165
Minimum	2.097117
Maximum	8.887282
Sum	4779.256
Count	1000

c) sheet thickness *d*=4 mm



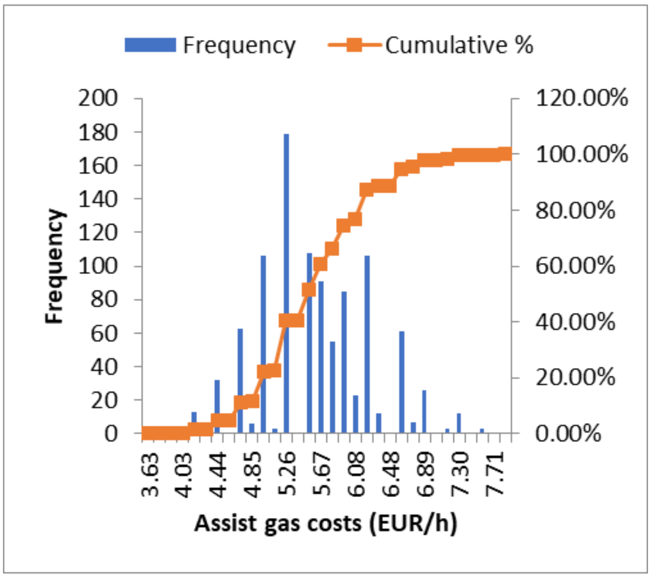
Mean	6.748438
Standard Error	0.033203
Median	6.623832
Mode	7.394187
Standard Deviation	1.049985
Sample Variance	1.102468
Kurtosis	0.126533
Skewness	0.465115
Range	6.023156
Minimum	4.24845
Maximum	10.27161
Sum	6748.438
Count	1000

d) sheet thickness *d*=6 mm



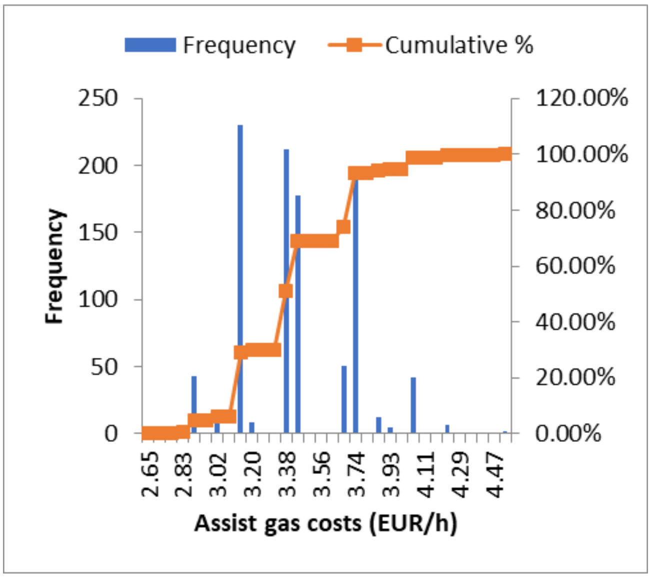
Mean	7.001723
Standard Error	0.019241
Median	6.852854
Mode	7.514009
Standard Deviation	0.608445
Sample Variance	0.370205
Kurtosis	-0.25888
Skewness	0.160757
Range	4.156903
Minimum	5.241964
Maximum	9.398866
Sum	7001.723
Count	1000

d) sheet thickness *d*=8 mm



Mean	5.542358
Standard Error	0.020939
Median	5.440961
Mode	5.173226
Standard Deviation	0.662144
Sample Variance	0.438435
Kurtosis	-0.10508
Skewness	0.265111
Range	4.219684
Minimum	3.626131
Maximum	7.845815
Sum	5542.358
Count	1000

e) sheet thickness *d*=12 mm

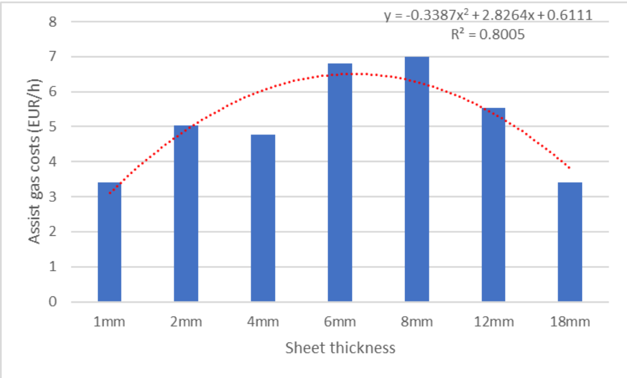


Mean	3.417831
Standard Error	0.009012
Median	3.378167
Mode	3.378167
Standard Deviation	0.284996
Sample Variance	0.081223
Kurtosis	0.070195
Skewness	0.344934
Range	1.882585
Minimum	2.651221
Maximum	4.533807
Sum	3417.831
Count	1000

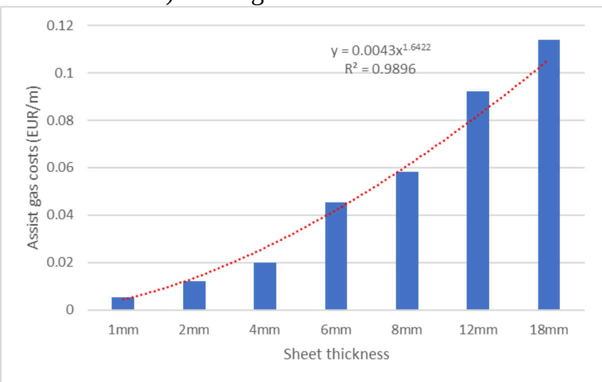
f) sheet thickness *d*=12 mm

Fig. 1 *Distributions of assist gas costs with descriptive statistics for different sheet thicknesses*

Analysis of results also reveals that with an increase in sheet thickness up to 8mm, average assist gas costs increases and afterwards, due to lower assist gas flow in laser oxygen cutting, assist gas costs decreases (Figure 2). The relationship can be represented with quadratic polynomial model having high coefficient of determination which indicates good model's explanatory power.



a) Assist gas costs in EUR/h



b) Assist gas costs in EUR/m

Fig. 2 *Analysis of average assist gas costs with respect to sheet thickness*

Although, based on Figure 2(a) one might think that cutting 18mm thick sheet is economically nearly equal to cutting 1mm thick sheet, given that recommended cutting speeds significantly decrease with an increase in sheet thickness, there is actually constant increase in assist gas costs in EUR per cut meter with an increasing in sheet thickness as given in Figure 2(b).

According to the well-known model for the estimation of assist gas consumption it is clear that assist gas consumption, and related assist gas costs, linearly increases with an increase in gas pressure, however any increase in nozzle diameter size results in nonlinear rise in assist gas consumption (costs).

However, given recommended interval values for main laser cutting parameters [9] one can apply sensitivity analysis using developed stochastic simulation model so as to analyze the effects of variation of both input parameters, i.e., assist gas pressure and nozzle diameter, on resulting change in assist gas costs. To this aim, one factor at a time (OFAT) design was conducted in the manner that one parameter was varied while the second was set at constant level (recommended intermediate level). For each sheet thickness 1000 simulation runs were performed and as an output, difference between maximal and minimal assist gas costs, was observed (Figure 3).

As could be observed from Figure 3, for sheet thicknesses up to 6mm, when nozzle diameter is set at recommended intermediate value and assist gas pressure is arbitrarily changed within the recommended limits, resulting assist gas costs are lower. Therefore, one can conclude that nozzle diameter has a more pronounced effect on the resulting assist gas costs in comparison to the assist gas pressure.
Eltawahni et al. [3] noted that the main factor affecting operating cost in CO_2 laser cutting of AISI 316L stainless steel is nozzle diameter. However, for sheet thicknesses above 8mm, there is no significant difference in resulting assist gas costs which may be attributed to the narrower recommended limits for the nozzle diameter. Anyway, for low-cost CO_2 laser cutting one can recommend firstly select as small as possible nozzle diameter and then determine adequate assist gas pressure which would ensure at the same time good quality cuts.

Given that in laser oxygen cutting exothermic heat and absorbed laser energy are both used in the cutting process and that the total cutting energy decreases with increase in the cutting speed [11], one need to carefully select cutting speed as well as laser power to cutting speed ratio.

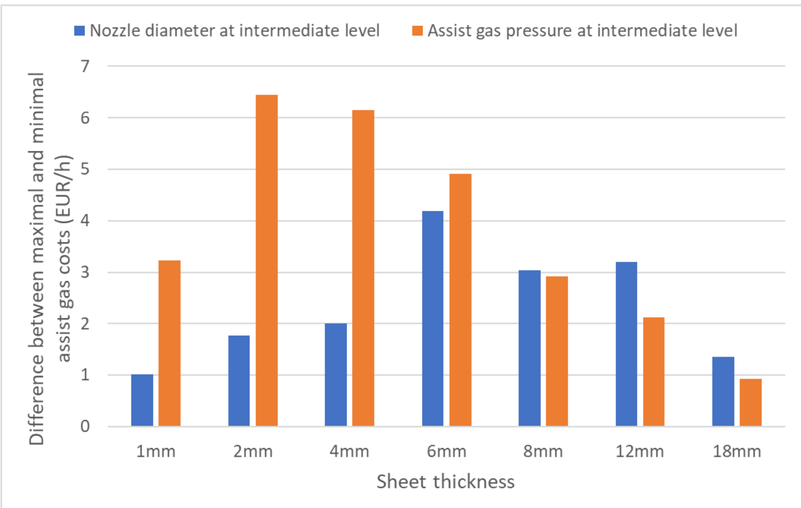


Fig. 3 *Results of sensitivity analysis*

4 CONCLUSION

The simulation of the laser cutting process planning, in terms of selection of different cutting regimes, can be of great use given it enables estimation of considered process performances and analysis of the effects of in independent variables on the results. In this paper stochastic simulation model for estimation of assist gas costs in CO_2 laser oxygen cutting of mild steel was developed. For the definition of model and its parameters empirical formula for estimation of assist gas consumption and industrial recommended interval values for main laser cutting parameters were considered, wherein normal distribution is set for the input parameters. The developed stochastic simulation model randomly sampled from distributions for each of the model parameters and based on obtained results of descriptive statistics and conducted analyses the following conclusions may be drawn:

- For thinner sheets assist gas costs are more variable due to broader recommended process windows, which indicates necessity for careful selection of process parameter values in order to achieve cost savings.
- If process planners consider equal various laser cutting regimes, which are being arbitrarily chosen within the recommended interval values, there may exists significant difference in resulting assist gas costs (4 or 5 times higher) with the tendency for this difference to decrease with increasing sheet thickness.
- The dependence of average assist gas costs on sheet thickness follows power model.
- Nozzle diameter has a more pronounced effect on the resulting assist gas costs in comparison to the assist gas pressure, particularly for thinner sheets.
- Low-cost CO_2 laser oxygen cutting does not imply high quality cutting, however through process optimization one can identify laser cutting conditions which represent best trade-off solutions for a particular case study.

Development of stochastic simulation models for the analysis of assist gas costs, as major sources of costs, in CO_2 laser fusion cutting of stainless steel and aluminum will be in focus for the future research.

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APPLICATION OF DIGITAL SLIDING MODES TO SYNCHRONIZATION OF THE MOVEMENT OF SEVERAL PNEUMATIC RODLESS CYLINDERS

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Abstract

The paper highlights the problem of synchronized piston movement of several pneumatic cylinders without a rod. This problem occurs in many machines and robots, especially in the field of material handling. The control system proposed in the paper for synchronization is designed using variable structure control system theory. The control algorithm is based on the digital sliding mode. The goal of control synthesis is to achieve the movement of the system in the state space on a certain surface for higher order systems. For second-order systems, a specified surface is converted into a line. It is assumed that the measurement of the state coordinates (position and velocity of the piston) is possible directly on the rodless cylinders. Measurement of compressed air flow and pressure is ignored for operational purposes. It was shown that such a system provides fast synchronization of the piston movement of rodless cylinders under different initial conditions (load and/or position) by computer simulation in Matlab software.

Keywords*: rodless, cyilinder, pneumatic, synchonization, digital, sliding mode.*

1 INTRODUCTION

Rodless pneumatic cylinders are widely used in flexible machine automation, production, and logistics processes. Pneumatic rodless cylinders are often part of various manipulators and robots. Very often, two or more rodless pneumatic cylinders need to move synchronously. As these rodless cylinders and their pistons may have different initial positions and different initial loads, it is necessary to synchronize further movement to a specific position value as quickly as possible.

The problem of rapid synchronization of the motion of rodless cylinders is particularly pronounced in the operation of Cartesian structure robots since they use rodless cylinders for their operation. An ordinary Cartesian structure robot consists of two rodless cylinders as a base, Fig. 1. If the movement of the robot base is not properly synchronized, the upper actuators may be skewed and thus lead to imprecise movement.

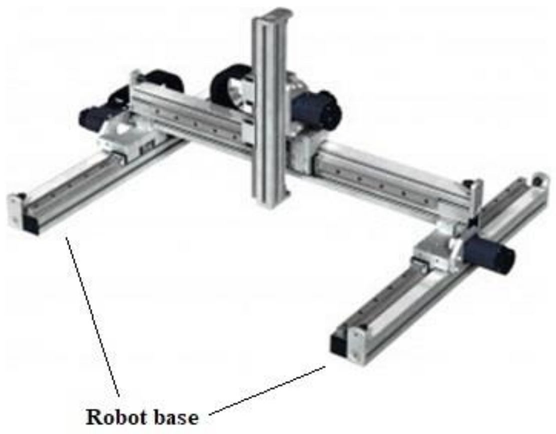
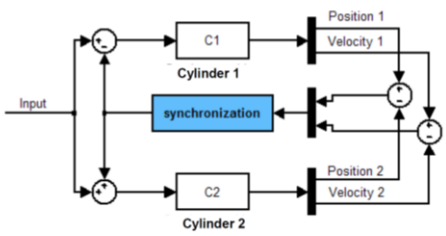
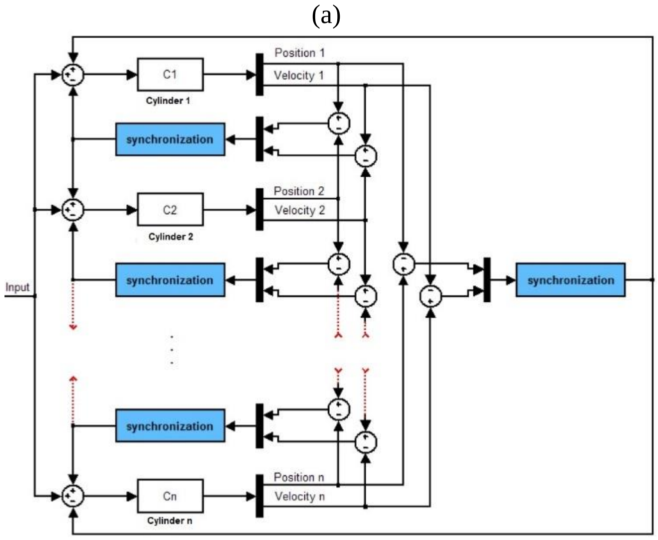


Fig. 1 *Robot of Cartesian structure*

Unbehauen and Vakilzadeh [1,2,3,4] were among the first to deal with the problem of synchronous movement of actuators. They studied the synchronization of different actuators and used conventional P, PI and PID controllers.



(a)



(b)

Fig. 2 *Synchronization system schematic representation: a) two rodless cylinders, b) several rodless cylinders*

The basic idea for actuator synchronization in this paper is presented in Fig. 2.

Fig. 2a shows a synchronization system with two rodless pneumatic cylinders. The reference signal is fed into the input of the system. The synchronization control signals of the rodless cylinders C1 and C2 result from the sum and subtraction of the reference signal and the feedback signal. The feedback signal is generated by the control module (synchronizer) blue rectangle in Fig. 2a. The feedback signal is generated as a function of the difference between the state vectors (position and velocity) of the piston rodless cylinders C1 and C2.

Fig. 2b shows a synchronization system with more than two rodless pneumatic cylinders. The sinhronization control signals of the cylinders C1, C2, …, Cn result from the sum and subtraction of the reference input and the feedback signals. The feedback signals are generated by the control modules (synchronizers), blue rectangles in Fig. 2b. The feedback signals are generated as a function of the difference of the state vectors of the neighboring rodless cylinders (C1 and C2, C2 and C3, …, Cn-1 and Cn, Cn and C1).

The proposed synchronization algorithm for several rodless pneumatic cylinders proved to be better in terms of a shorter synchronization time than an algorithm in which any one cylinder can be the reference cylinder while others are synchronized with it. This is because during the proposed synchronization scheme, at the very beginning of the synchronization some of the rodless cylinders move in one direction while others move in the opposite direction. In the case when one rodless cylinder is the reference and the others are synchronized with it, the synchronization period is longer because the others are only synchronized with the reference and not with each other.

The paper is structured as follows: The second part explains the method for creating a mathematical model of control objects, rodless pneumatic cylinders and proportional valves. The third part gives an overview of the control algorithm based on [5,6,7]. The fourth part presents the application results of the control algorithm in comparison to conventional algorithms [1,2,3,4] using a computer simulation in the Matlab software.

2 MATHEMATICAL MODEL OF THE SYSTEM

A pneumatic servo system with several rodless cylinders which is considered in this paper is shown in Fig. 3.

Servo system for synchronization consists of n double-acting pneumatic rodless cylinders with the designations 1.0, 2.0, …, n.0 and proportional valves 5/3 with electrical activation with the designations 1.1, 2.1, …, n.1 for each rodless cylinder.

The designations for the external loads are F_1, F_2, … F_n, and the absolute pressures in the chambers of the individual rodless cylinders are P_{i1}, P_{i2} and P_{in}, where i=1, 2. P_S is the absolute pressure supply and u_1, u_2 and u_n are the input signals of the proportional valves supplied by the synchronization block.

The rodless cylinder ports are connected by tubes to a proportional valve. The movement and speed of the rodless cylinder piston is achieved by varying the compressed air flow in and out of the respective rodless cylinder chambe. In this paper, non-linearity in the compressed air flow through the tubes is ignored.

A proportional valve ensures this variation of the compressed air flow by means of a suitable control algorithm. The digital sliding mode control is used to control the synchronization system in Fig. 2.

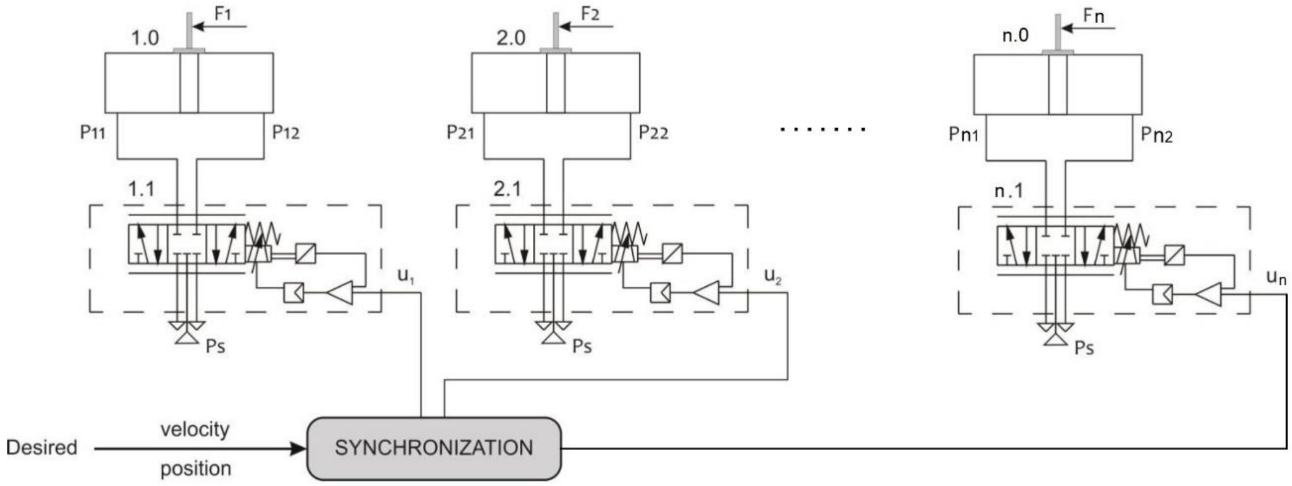


Fig. 3 *Pneumatic scheme of the servo system for synchronization with **n** rodless cylinders*

The mathematical model of the system in Fig. 2 is completely non-linear and it is difficult to use this model for the design of control systems. In this paper, the linearized second-order mathematical model is used to design the controller. The development of the second order linearized mathematical model (transfer function of each rodless cylinder and its proportional valve) is explained in detail in the papers [5,7]. The linearized second-order mathematical model for a rodless cylinder and its proportional valve can be represented as follows:

$$G(s) = \frac{K_p}{s^2 + K_1 s + K_2} \quad (1)$$

where K_p, K_1 and K_2 are coefficients of transfer function, and they depend on:

- rodless cylinder dimension,

- tubing and proportional control valve,
- compressed air characteristics and some other parameters,

The second order linearized mathematical model given by transfer function (1) can be transform in state-spase model like:

$$\dot{x} = Ax + bu = \begin{bmatrix} 0 & 1 \\ -K_2 & -K_1 \end{bmatrix} x + \begin{bmatrix} 0 \\ K_p \end{bmatrix} u \qquad (2)$$

All coefficients are explained in papers [5,7] in detail.

3 DIGITAL SLIDING MODE CONTROL ALGORITHM

For the purposes of synchronizing the movement of rodless cylinders in this paper, the control algorithm belongs to the group of digital control algorithms with variable structure. The aim of the control design is to achieve the movement of the system in the state space on a given surface in higher order systems. For second-order systems, a specified surface is converted into a line. This is possible if the transfer of the system state from any initial state to the specified surface and the subsequent movement on this surface in the sliding regime is ensured. Then the phase trajectories of the system all merge into the given surface. Under these conditions, the asymptotic stability of the system is also ensured, and the system is brought to equilibrium according to a given trajectory, which may also have properties of optimality.
The movement of these systems has three phases: (I) the phase of reaching the surface; (II) the phase of the sliding regime; (III) the phase of steady state, Fig.4.

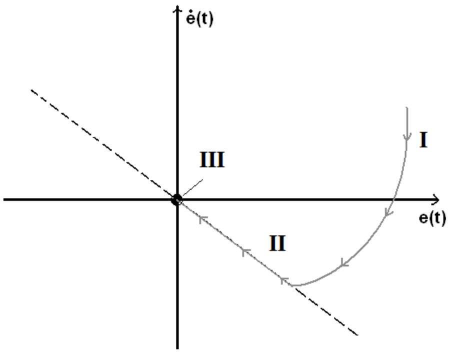


Fig. 4 *The movement of the system*

The condition for system movement, Fig.3, is:

$$s(x)\dot{s}(x) < 0 \qquad (3)$$

where s(x) is sliding surface.
In this paper, a digital sliding mode control algorithm is used to fulfil condition (3). This control consists of two components: a relay component and a linear component. A relay component ensures that the state of the system is transferred to the vicinity of the sliding surface without intersecting it (no chatering). A linear component brings the state of the system into the range s(x)=0.
First, it is important to perform a temporal discretization of the model (1) with a sampling period of Td, as:

$$A_\delta(T_d) = \frac{e^{AT_d} - I_n}{T_d}, \quad b_\delta(T_d) = \frac{1}{T_d}\int_0^{T_d} e^{A\tau}\, b\, d\tau \qquad (4)$$

The mathematical model is now:

$$\delta x(kT_d) = A_\delta(T_d)x(kT_d) + b_\delta(T_d)u(kT_d) \qquad (5)$$

Switching function for digital sliding mode control is:

$$s = c_\delta(T_d)x \qquad (6)$$

where,

$$c_\delta(T_d) = [c_1(T_d) \quad 1]P_1^{-1}(T_d) \qquad (7)$$

And,

$$c_1(T_d) = -\frac{e^{-\alpha T_d} - 1}{T_d}, \quad \alpha > 0 \qquad (8)$$

$$P_1^{-1}(T_d) = QW \qquad (9)$$

$$Q = [b_\delta(T_d) \;\; \cdots \;\; A_\delta^{n-1}(T_d)b_\delta(T_d)]_1^{-1} \qquad (10)$$

$$W = \begin{bmatrix} a_1(T_d) & \cdots & 1 \\ \vdots & \ddots & \vdots \\ 1 & \cdots & 0 \end{bmatrix} \qquad (11)$$

Now, the control low is represented by equation:

$$u_c = -c_\delta(T_d)A_\delta(T_d)x(k) - \Phi(s(k), X(k)) \qquad (12)$$

Function $\Phi(s, X)$, in control low (12), can be defined like:

$$\Phi(s, X) = min\left(\frac{|s|}{T_d},\; \sigma + \rho|s|\right) sgn(s) \qquad (13)$$

Defining sliding mode reaching dynamics is by parameters σ and ρ and they must be chosen to provide short reaching phase. Their recommended values are:

$$0 \leq \rho T_d < 1, \quad \sigma > 0$$

4 SYNCHRONIZATION OF THE SYSTEM WITH SEVERAL RODLESS PNEUMATIC CYLINDERS

As proof of the accuracy of the synchronization algorithm with digital sliding mode control shown in Fig. 2, a pneumatic system with four double-acting rodless cylinders is used in this section.
The system model of each pneumatic rodless cylinder and its proportional valve is represented in space state form by equation,

$$G(s) = \frac{4{,}065}{s^2 + 180s} \qquad (14)$$

The sliding surface coefficient is calculated using equation (7), for α=15s-1. Parameters ρ and σ are taken to be 0 and 24, respectively.
Vectors $c_\delta(T_d)$ and $c_\delta(T_d)A_\delta(T_d)$ are:

$c_\delta(T_d)$= [-16.428 -2.0356],

$c_\delta(T_d)A_\delta(T_d)$= [0 87.847].

The different starting (initial) positions are reflected in the fact that the piston of the first rodless cylinder C1 is in the starting position x_1=0.1m, the piston of the second rodless cylinder C2 is fully retracted, i.e., x_2=0m, the third rodless cylinder is in the starting position x_3=0.15m and the fourth rodless cylinder is in the starting position x_4=0.05m.
The problem of synchronization is to reach the same piston positions of all rodless cylinders (x_1, x_2, x_3 and x_4) in a short time and to continue moving without position differences.
Fig. 4 shows the work of the system when synchronization is performed with P controller.

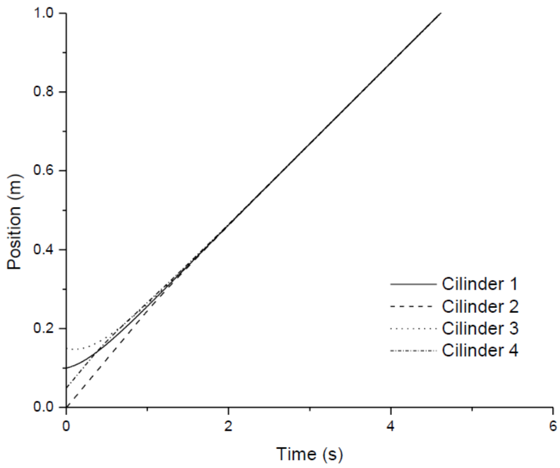


Fig. 5 *Simulated results of the pneumatic rodless cylinders positions by P controller*

Fig. 5 shows the result of the synchronization when digital sliding mode control is applied.

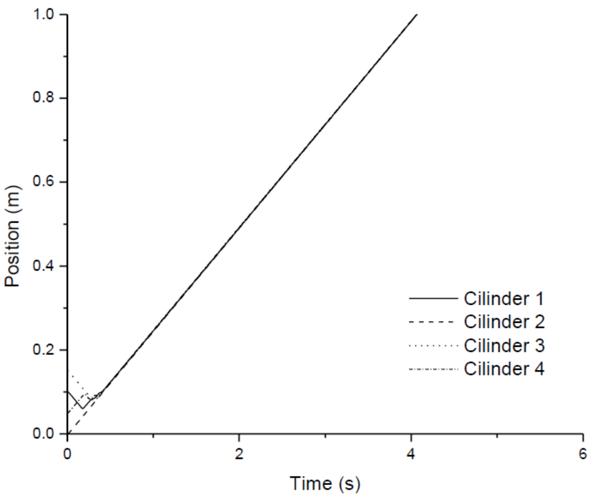


Fig. 6 *Simulated results of the pneumatic rodless cylinders positions by digital sliding mode controller*

It is shown that the digital sliding mode control is much better suited for synchronization than the P-controller, since the digital sliding mode control achieves synchronization faster than the P-controller.

CONCLUSION

The paper deals with the problem of synchronizing the operation (piston movement) of several rodless pneumatic cylinders. A synchronization scheme and a digital sliding mode control algorithm were given to solve this problem. The digital sliding mode control algorithm serves its purpose as it ensures the synchronization of the operation of the rodless pneumatic cylinders within a short period of time, which was demonstrated and explained in Section 4.
The synchronization algorithm for controlling the operation of several pneumatic rodless cylinders proved to be better in terms of shorter synchronization time than an algorithm in which one rodless cylinder can be the reference actuator while the others are synchronized with it.

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APPLICATION OF STRATEGIES IN THE LOGISTICS OF PRODUCTION

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Abstract

Logistics of production covers many areas within the production environment such as: procurement, receipt of goods, handling of semi-finished products, inventory control, storage of finished products as well as materials and distribution to end customers. In this paper, logistics of production will be described as an important factor in the production process and manufacturing logistics concepts that were created to facilitate and improve the manufacturing process in industry. The paper will list the types of logistics strategies, their characteristics and the way they work in production. These concepts are often used together to achieve maximum efficiency and competitive advantage in the production function. All these concepts together make production logistics a dynamic and important process that is necessary for successful business in the manufacturing sector.

***Keywords**: Logistics, Production, Strategies, Practical application.*

1 INTRODUCTION

Through the development of technology and the globalization of the market, logistics has become even more necessary and important, because it is necessary to effectively manage complex networks of suppliers, manufacturers, distributors and traders around the world. Inventory management, optimization of transport routes, tracking of deliveries and quick response to changes in demand have become key aspects of business. For these reasons, the existence of logistics as an economic discipline has become necessary, as well as its constant improvement and expansion of business scope.

Special attention should be paid to production logistics because it plays an important role in ensuring the economic flow of materials, resources and information during the production process. Through well-thought-out planning, organization and management, production logistics helps improve the production process, then reduce costs, shorten production time and increase product quality.

The constant growth and development of demand and markets for a wide variety of products required the improvement of logistics as an economic branch, without which the processes of production as well as distribution and sales would be practically impossible.

Possible couplings of production logistics with supply and distribution logistics are dependent on many factors and decisions related to production. Very often, the production technology applied at a production company does not allow for production without stocks.

In this paper, at the beginning, a short explanation is given related to production logistics, its importance and concepts that help in the functioning of a business organization. In the following part, in each individual chapter, the most important strategy is highlighted and explained in more detail, as well as its application in practice.

2 PRODUCTION LOGISTICS

Production can only be successful if it meets the needs of customers and successfully competes on the world market. In addition, every national company must base its development on efficient production. Modern production is increasingly complex in terms of the application of technology or production procedures or operations. In a complex production process, logistics is particularly important. Production logistics is mostly related to the distribution of supplies in the initial part of the production process and increasingly includes the use of modern information technologies.

In order for the production process to be successful and efficient, it is necessary to carry out the procurement process in a timely and adequate manner. Even during procurement, a great deal of coordination is required with preparation services, warehouses, and especially production. Production preparation is also an important factor of the logistics production system. The quality of the preparation already depends on the development of the product, which defines all technical, commercial and financial criteria. As part of logistics in production, the question of the quality of not only the product, but also the entire process and procedures of preparation, procurement, application of technologies, speed of production and the like is particularly important.

The logistics of production includes, among others:

- considerations: produce or buy, jointly with procurement,
- production structure according to logistical aspects,
- production planning and production control,
- shaping the physical and IT flow of production.

In this case, logistics is a concept that includes the flow of goods from the supplier, through the production plant, to the end customers. Logistics should cover the activities of procurement of reproduction material, distribution in the production process itself, as well as delivery to customers. Thus, production logistics covers many areas within the production environment such as: procurement, receipt of goods, handling of semi-finished products, inventory control, storage of finished products as well as materials, and distribution to end customers.

2.1 The concepts of production of logistics

The logistics strategy relates to the process of fulfilling the requirements of customers and is defined by a series of decisions on the key logistics domains of operation of the company in order to attain sustained profitability.
The logistics of production includes a number of key concepts and principles used to effectively manage production processes. The basic concepts of logistics are:

1) Just in time (JIT) this concept refers to the delivery of materials exactly at the moment they are needed for production, in order to reduce inventories and increase efficiency,
2) Total Quality Management (TQM) focuses on achieving high product quality through quality management in all stages of production,
3) Lean production - this approach advocates the elimination of all unnecessary operations and resources in production in order to reduce losses and increase efficiency,
4) Kanban - a system that uses visual signals to manage the flow of materials and information in the production process,
5) Agile manufacturing - focuses on flexibility and the ability to quickly adapt to changes in demand and production requirements
6) Production cycle - a concept that refers to the time it takes to turn raw materials into a finished product,
7) Inventory management - one of the key concepts to avoid shortages and overstocking
8) Supply chain management - includes the coordination of all activities involved in the supply of raw materials, production and delivery of finished products,
9) Production planning and control - includes production planning, allocation of resources and monitoring of plan execution in order to achieve production goals,
10) Automation and technological innovation - the integration of automation and advanced technologies, such as Industry 4.0, which play a key role in modern production logistics concepts.

3 CONCEPT “JUST IN TIME”

This principle was introduced to achieve the idea of production without creating inventory. If the practical methods and methodology that make up the essence of the system are not understood, then "just in time" has no meaning in itself. Therefore, Just in time production means the production of finished products exactly on time, in order to meet the customer's request, then the production of component parts as the need for them goes, exactly on time, when it is necessary to assemble them into finished products, as well as the procurement of materials as how they arrive after them, and exactly on time, so that parts could be produced from them in a timely manner.
Just in time production means producing only what is required, in the smallest possible batches, with "zero errors" and in the shortest possible time. Sometimes this production is also called warehouseless production.

Fig. 1 *Just in time concept in practice*

During production, each process produces only what is needed for the next process. When it was first introduced, this approach was a radical departure from conventional manufacturing systems, which require large inventories to push as much product as possible through production lines, regardless of actual demand. The customer is the one who really "pulls" the production. When a problem occurs, the equipment stops working immediately, preventing the production of defective products.
The advantages of 'Just-in-Time' philosophies enable Toyota's production system to produce vehicles efficiently and quickly, one by one, with superior quality and to fully satisfy customer requirements. By producing products only when they are needed and with strict quality control, Toyota's production system eliminates waste and therefore reduces the consumption of energy, raw materials and other resources, making it a powerful ally in Toyota's pursuit of sustainability. For customers, this means top-quality cars with a wide range of options available, which can be delivered faster and at a significantly lower price.
The JIT strategy has attracted more attention in a short time than any strategy known so far. The main reason for paying attention to the JIT strategy is the success of most of the products of the Japanese economy. In Japanese, this term means "well-planned in time". There are many interpretations of this definition, and it basically means that every process should be supplied with the right elements, in the right amount and at the right time.
JIT is a new philosophical approach to the production and transportation process. The basis of the JIT strategy is the overall observation of the reproduction process with the aim of having the right goods in the right quantity and quality at the right place at the right time. So, the JIT concept implies the movement of products according to a certain technological procedure from the procurement of raw materials and other materials needed for production, through the production process, all the way to the end user.
The idea of just in time production does not refer just to some parts of an organization, rather, it is for all parts and units of all kinds of organizations. Just in time production system is something more than goods management and materials transportation. It is a philosophy and thought which aims to delete wastages completely and tries to avoid materials scraps in all activities.

4 "KANBAN" CONCEPT

Using the Kanban method means applying a holistic way of thinking about your services with a focus on improving them from your customers’ perspective. With the Kanban Method, you visualize invisible knowledge work and how it moves through a workflow. This helps to effectively operate your business, including understanding and

managing risks in delivering your services to the customers. With Kanban, you and your business will develop an adaptive capability over time to respond better and faster to changes in your customers' needs and expectations or within your business environment.
Kanban is a system that is a shadow of Just in time production and is typical of numerous methods and techniques that were created in Japanese industry, primarily in the Toyota system, where it found great application. The Kanban system represents a comprehensive, integral production management system at the so-called micro level, in the workshop and at workplaces. As a production management system, kanban covers production management, inventory control, quality control, procurement and distribution, and even a worker motivation system. The Kanban system usually works harmoniously in production, in accordance with the total quality control system, as another major Japanese innovation in production.
In the complex problems of production management, new systems are being developed and applied today, which deal with production management at the system level or, on the other hand, those systems deal with production management at lower levels in workshops. Thus, recently, a new production management system called the Kanban system was developed and put into practice. The word kanban is the Japanese word for the identification card of a particular material. This material map, that is, the Kanban system, aims to:

1) They identify the contents of the container (pallet) of materials
2) Place a new order for materials when the pallet is empty.

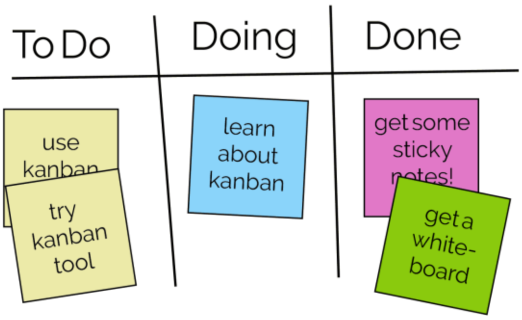

Fig. 2 *Concept of Kanban*

Within the production management system, Kanban is a means to achieve the so-called just in time in production. This means that something is well planned in terms of time in production, therefore Kanban represents a decentralized approach to management in the area of ordering and monitoring materials in production. The goal of introducing this system is to plan the material well, to monitor and control the quantity, and to order new material for production needs at the right time. the production process is supplied with the right elements, in the right quantity and at the right time.
The Kanban system is inspired by the simple replenishment system used in large department stores in self-service departments, where the customer selects the goods they want on the shelves and picks them up. In order for the system to work well, care must be taken to keep the shelves full at all times. This logic was transferred to the organization of production. Modern production management systems start from the fact that production systems work on the principle that products are sucked into production managed by real needs.

5 LEAN PRODUCTION

When unnecessary and unprofitable activities in the production process are eliminated, and attention is focused exclusively on what creates value from the customer's point of view, the Lean production system enables the maximum quality of the production process to be achieved, in order to establish and maintain a balance between quality and timely satisfaction of customer needs and own profitability, in modern business conditions.

The introduction of the Lean production system resulted in a continuous process of constant systematic identification and elimination of redundant phenomena in business, i.e. the removal of everything that does not represent importance and value from the customer's perspective. Thus, in crisis conditions, costs are significantly reduced and it is possible to achieve small but long-term financial benefits, which is the key to sustainable and long-term production.

Fig. 3 *The concept of LEAN technology at Toyota*

No organization can completely avoid logistics costs. The next best option is to make it as cheap as possible while still providing an acceptable level of customer service. This approach is generalized as "lean" logistics.

The goals of the "lean" strategy are to perform all necessary operations while using as few resources as possible (people, space, inventory, equipment, time, etc.). It organizes the efficient flow of materials to eliminate losses, tracing the shortest path, minimum inventory and minimum total costs. Lean operations were first used in the automotive industry, led by Toyota. The work was concentrated on "lean" production, but this approach gave such good results that it found application in other parts of the organization.
Some experts believe that "lean" operations may be retained in the mass production car industry, but may not be transferred to other supply chains. This is because "lean" operations may not function satisfactorily in changing and unstable conditions. The alternative is a more flexible strategy based on agility.

6 „KAIZEN“ CONCEPT

Kaizen is not focused on fundamental process improvements, because they are very difficult to achieve, but on small but constant improvements. Small constant improvements, when viewed over a long period, provide big savings and big improvements in all the processes of the organization. And many military organizations recognized the advantages of Kaizen methods and techniques and implemented them in their processes and activities. In military organizations, Kaizen gives the best results if it is implemented at the lowest hierarchical (tactical) level. Value stream analyzes at the tactical level of military organization point to specific, harmful and unhelpful activities that would normally not be noticed if the analysis were performed at the operational or strategic level. This is the most important advantage of Kaizen that favors it for application in military systems.

Knowing the economic development of Serbia and market conditions, it can be concluded that the application of the Kaizen concept in as many Serbian companies as possible would bring faster progress of the Serbian economy and betterment of the whole society. This is confirmed by data from the factory Japan Tabacco International a.d. Senta, one of the few companies in Serbia that fully applies Kaizen management. Since the beginning of the implementation of the Kaizen concept, productivity in the factory has increased by as much as 52 percent, and the amount of scrap has decreased by 57 percent.

Fig. 4 *The concept of Kaizen*

There are two essential prerequisites for implementing Kaizen in domestic practice. The first is to change our habits and way of thinking. Our biggest enemy is our fixed mindset. We have to abandon the motto that we often adhere to in practice: "If something works, don't touch it". Kaizen says the opposite: "Everything, including what works, can and must be improved." The alternative to non-advancement is stagnation and a decline in the system's operational capability".

Kaizen is a Japanese management technique that is focused on improvements through various small movements, steps and ideas to increase labour productivity, business efficiency, product and service quality and other operational and financial performance. After useful implementation in a numerous Japanese companies, this technique has sparked great interest among academic researchers and practitioners in the sense of achieving high-quality outputs with minimal efforts. Kaizen became a popular and applicable management tool in other countries around the world.

7 CONCLUSION

Throughout history, logistics has gone through great development and improvement, first in the military, and then in all other segments of society. Without logistics, there would be no quality production, and therefore no products that are necessary for the life of modern man. That's why production logistics reached its rise and improvement as well as the introduction of different strategies and concepts that enabled production to get a larger scale, better quality, shorter time of the production process itself and the most important economically acceptable costs that bring better profit for the producer himself.

Due to its widespread distribution, production logistics will develop and improve even more in the coming period, it will have to follow the increasingly rapid development of information technologies and production technologies in general, so that there will always be room for progress and development in this segment of the economy. Production logistics is a key factor successful business in today's business environment. The production process needs to be optimized together with the supply chains, as well as the proper management of the inventory that is of utmost importance for the smooth production that companies need to achieve in order to achieve competitive advantages.

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APPLICATION OF MACHINE LEARNING IN THE TRAFFIC LIGHT CONTROL

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Abstract

Today's concepts and technologies focus on the principles of interconnection, digitization and automation. In this context, machine learning (ML) represents very suitable algorithms for solving non-linear and complex phenomena, where future events are predicted based on behavior patterns and data correlation, thus facilitating the adoption of adequate and timely decisions. ML models have found implementation in solving the problem of traffic congestion at intersections by forming an adaptive signal plan. This article explores the current state and systematically analyzes proposed models for the formation of an adaptive signal plan at an intersection using ML and deep learning (DL). In the paper, several interesting researches are selected and their results are presented in comparison with a fixed way traffic signal control (TLC).

Key words*: machine learning, deep learning, traffic, intersection*

1 INTRODUCTION

Nowadays, social networks, smartphones, tablets, GPS devices, sensors and many other devices are sources that generate every second a large amount of unstructured data. The amount of data created, recorded, copied and used worldwide is increasing exponentially.

However, most traditional data analysis tools, such as relational databases, are unable to store and manage such highly complex data. ML has found application in analyzing the collected data to provide meaningful correlations and provide predictions to the decision maker. In general, ML teaches computers to learn from experience, that is, it uses computational methods to "learn" information directly from data without relying on a predetermined equation as a model [1].

Depending on the learning method, four categories are distinguished: supervised, unsupervised, semi-supervised and reinforced learning. In supervised learning, algorithms learn the relationship between input values and patterns and try to predict output values based on test data. Unlike supervised learning, in unsupervised learning, labels are not available, so algorithms try to identify patterns on the test data and cluster the data or predict future values [2]. Semi-supervised learning represents a combination of the above two learnings. Reinforcement learning (RL) algorithms attempt to predict the output of a problem based on a set of tuned parameters. Then, the output parameter that becomes the input is calculated, and the new output is calculated until the optimal output is found. Representatives of this learning are artificial neural networks (ANN) and DL, which have found application in real-time decision making. DL usually consists of multiple levels of representation, where an algorithm is constructed by assembling non-linear modules that transform a single input to a higher and more abstract level. With a sufficient number of transformations, the models are able to learn extremely complicated functions and structures [3]. DL approaches have shown high performance in discovering the structure of high-dimensional data in many fields, such as computer vision, natural language processing, speech recognition, and bioinformatics. The data used for ML consists of a set of variables. Two parameters dominate when using ML techniques: how computationally intensive it is and how fast the chosen technique is. Conceptually, ML algorithms can be viewed as programs for searching a large space - data, guided by training experience, where the goal is to find a program that optimizes the output variable, that is, the solution. ML has advanced dramatically over the past two decades, from a laboratory curiosity to widespread adoption for commercial use. The application of ML methods can be found in various branches of science, technology and commerce, leading to easier decision-making based on evidence in many spheres of life, including healthcare, manufacturing, traffic, transportation, logistics, education, financial modeling and marketing.

The increase in the number of inhabitants caused an increased use of vehicles, while the road infrastructure grows relatively slower, which leads to an imbalance between the number of vehicles and the capacity of the roads, resulting in traffic congestion, and therefore an increase in the travel time of road users. Regulating urban traffic is one of the most important and challenging issues facing cities. The development of urban traffic regulation over the past few decades represents a race to keep up with the constant increase in the number of vehicles on the street. In order to detect the operational performance of the intersection, traffic flow, vehicle speed, density and occupancy of traffic lanes are used as indicators for determining traffic congestion [4], while the main traffic parameters of intersections are considered to be passing time, traffic speed and waiting time. Due to the infrastructural impossibility of building traffic roundabouts, solving conflict situations at level intersections has been solved for decades by using light signals. The time distribution of the right of use is carried out in accordance with the selected management criteria. The two basic criteria in the optimization of the operation of light signals are the time losses of vehicles at the signalized intersection and the capacity of the traffic lane, approach or intersection. Optimization methods have been successfully applied to shorten travel time by optimizing the parameters of the time of turning on light signals. Due to the availability of data, significant progress has been made in vehicle detection and communication, which have enabled a number of changes in the possibilities of city traffic regulation systems, from fixed signal plans to modern integrated systems [5].

The number of published research that presents new approaches to solving problems in the management of traffic lights using ML and DL techniques has been growing exponentially in the last decade (Figure 1). It should be noted that the analysis was performed for the subject area by searching titles, abstracts and keywords, where the authors included all types of articles with the restriction that they were published in English. This approach was used to get an impression of the state of the research field.

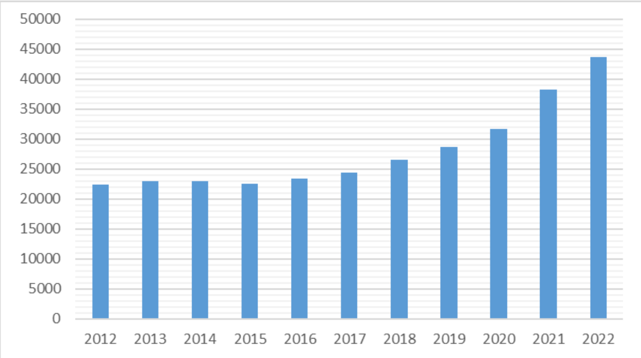

***Fig. 1** Overview of published works in the period 2012 - 2022 on the topic of application of ML and DL in TLC*

2 RESEARCH OVERVIEW OF ADAPTIVE INTERSECTION CONTROL

Advances in technology have enabled the implementation of advanced traffic signal control at the intersection. Using ML algorithms, signal timing can be predicted for each phase based on dynamic traffic demand. However, adaptive traffic signal control is site-specific, as traffic volume, traffic structure, and driver behavior vary from place to place. In this regard, researchers around the world have applied various technologies to design an efficient traffic management system.

The study [6] presented adaptive traffic signal configuration prediction for an isolated intersection in Tumakuru, a city in southern India, where the goal is to select one of eight ML models to predict traffic signal plans for each phase with two different types of classification input data of traffic (number for each type of vehicle) and volume of traffic by passenger car unit (PCU). PCU is used to convert unstructured traffic into structured traffic (all different types of vehicles are converted into cars). The proposed study is shown schematically in Figure 2. Data collection was carried out from a five-way intersection with permitted traffic in all directions from one approach road in one phase, through video recordings in the time period from 10:00 to 12:30. Subsequently, selected ML models were developed to predict an adaptive signal plan based on the traffic demand on the approach roads at the intersection. The implementation of the model was performed on the PyCharm platform, where 70% of the collected data was used for training, and 30% as a test set. After that, a comparative analysis was performed on the traffic signal plan predicted by each model using different performances in order to select the appropriate model for the isolated intersection.

To evaluate the effectiveness of the prediction ability, two cases were considered: green length prediction based on traffic classification in each phase and green length prediction based on traffic volume in terms of PCU in each phase. The comparison was made on the basis of mean absolute error and mean squared error. Although Linear Regression (LR), Ridge and Gradient Boosting Regression Tree (GBRT) showed almost the same predictive ability with small variations, based on the collected data, it was shown that GBRT is more suitable for designing an adaptive signal plan. In a similar way, the study [7] predicted the traffic flow in the intersection zone with the aim of proposing smart control of traffic lights. The study included the collection of data from 6 intersections for a duration of 56 days. The experimental results showed that the performances considered for the seven models (LR, GBR, MultiLayer Perceptron Regressor, Stochastic Gradient Descendent Regressor and Random Forest Regressor) do not different significantly, while the least time is needed for training using the Multilayer Perceptron Regressor model.

In contrast to the aforementioned studies, in research [8] an adaptive traffic signal control scheme was proposed for efficient management of dynamically fluctuating traffic flow. The paper proposes the application of (RL, which can effectively work with traffic flow models for adaptive traffic control [9]. In order to effectively identify traffic patterns, a deep neural network (long short-term memory network - LSTM) was used to capture the spatio-temporal representation of traffic conditions at the intersection. The LSTM network is specially adapted to time-series modeling and enables estimation-based signal control by long-term feedback from a given traffic state. The proposed adaptive signal control enables decision control based on the guidance of a trained neuron network after learning the optimal control strategy through multiple trial-and-error interactions between the controller and the intersection environment. In this research, the arrivals of vehicles at the intersection represent the time variable traffic demand curve obtained from historical data after which it was generated by Poisson distribution over 24 hours. In order to ensure the convergence of the RL algorithm, the "actor-critic" strategy was applied in the model to optimize the parameters of the LSTM network. The "actor-critic" algorithm effectively provides a compromise between optimality and speed of convergence. Considering that the traffic signal controller plays a key role in the construction of safe, efficient and ecological city traffic, in the study, vehicle delay is taken to evaluate traffic efficiency, based on which an objective function is constructed to minimize the total delay of vehicles approaching the intersection. In the proposed control scheme, the time frame is divided into several discrete time intervals and each time interval is indexed by t.

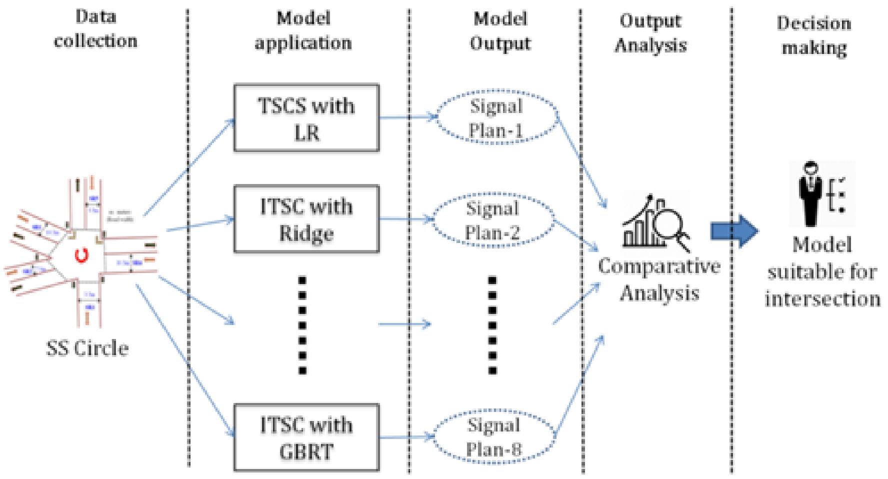

Fig. 2 *Schematic representation of the method [6]*

For each time interval t, signal control is considered for three phases: perception, decision making, and execution. In the perception phase, the controller first detects positions and vehicle speeds information in the time interval t through several types of smart sensors, such as millimeter wave traffic radar and computer vision based traffic monitors. In the decision-making phase, the controller gives an action between two choices: extend the current phase or move to the next phase based on the observed state s_t. The basic logic is that the trained neural network function can predict the optimal action when using the state s_t as input, where its internal parameters are obtained using RL through multiple interactions between the controller and the simulation environment. Finally, in the execution phase, the traffic light will execute the planned action in $1t$ seconds and start the next iteration for the time interval $t+1$. The traffic controller makes action decisions based on the representative state of the target intersection. The research proposed a method for collecting multidimensional information representing the traffic situation, in order to reduce the loss of information caused by partial observability. Although the number of vehicles at the intersection is time-dependent for the input data, the average delay for each vehicle and the dimensions are taken as a constant. The function approximation architecture adopted in the subject research is shown in Figure 3.

During the training process, the algorithm uses Adam's optimizer as a "gradient descent algorithm" with a learning rate of 0.0002 for "critic" and 0.0001 for "actor". The "critic" and "actor" networks use the same structure except for the output layer. The performance of the proposed traffic signal control was tested on the traffic simulator Simulation of Urban Mobility (SUMO) [10, 11], while the implementation of the LSTM network was performed using TensorFlow for function approximation.The study used data from the intersection in Stanford, USA. To train the parameters in the LSTM network using RL, a numerical experiment was performed for an arbitrary number of 200 simulated days, with the exploration rate decreasing from 1.0 to 0.0 linearly over the first 150 days, after which the agent stops exploring and exploits the environment to the fullest. The learning rates are 0.0002 and 0.0001 for "critic" and "actor", respectively. Evaluation of the efficiency of the algorithm in relation to the fixed-time controller was performed using the software tool Synchro [12]. Initially, the agent explores the environment and chooses actions randomly most of the time, which means that the agent's performance is poor and the size of the oscillations is large. As the training days progress, the agent learns more from experience and achieves lower cost, lower variance, and near-optimal and stable performance. Finally, after 83 days of training, the agent starts to approach the optimal value. In order to test the effectiveness of the RL controller, five indicators were compared namely fuel consumption, hydrocarbon emission rate, average speed, queue length and waiting time. It should be noted that waiting time is different from delay time.

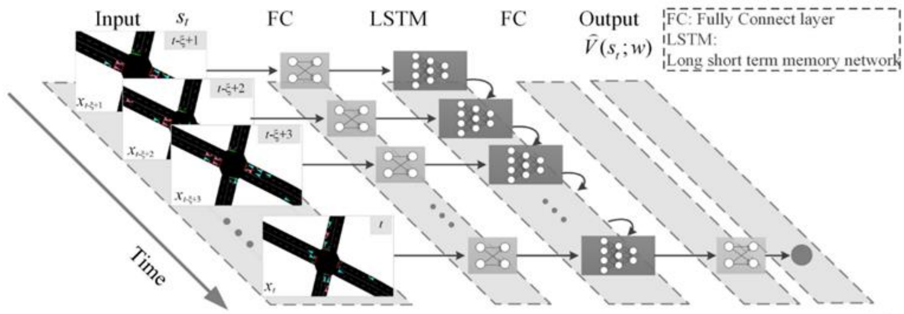

Fig. 3 *Schematic view of the LSTM network [9]*

The waiting time refers to the stopping time as a result of the red phase, while the delay time refers to the additional time required due to the way traffic signals are controlled. The reduction in vehicle delay time at intersections is numerically shown in Table 1 for 10 random samples, compared to the fixed-time optimized plans obtained using Synchro (SY).

Table 1 Comparative overview of the performance of RL and fixed signal plan Synchro [9]

	SY	RL	SY	RL	SY	RL	SY	RL	SY	RL
0	9.39	8.10	3.43	2.52	28.89	31.71	2.46	1.32	42.90	16.46
1	8.86	8.59	3.02	2.81	28.89	30.49	1.93	1.68	31.47	21.20
2	9.33	8.28	3.38	2.63	28.47	31.12	2.39	1.46	43.03	18.20
3	8.92	8.12	3.11	2.55	29.10	31.36	2.07	1.36	34.92	16.55
4	9.93	8.07	3.80	2.54	28.68	31.42	2.92	1.37	52.78	16.47
5	8.92	8.73	3.07	2.89	28.79	30.78	1.99	1.75	32.95	23.49
6	8.90	8.36	3.06	2.68	28.71	30.94	1.98	1.51	32.77	19.20
7	9.09	8.44	3.18	2.68	28.83	31.39	2.11	1.47	35.83	19.45
8	9.12	8.35	3.19	2.64	28.62	31.24	2.12	1.42	36.03	18.73
9	9.02	8.35	3.13	2.63	28.77	31.22	2.05	1.40	34.71	17.91
Mean	9.15	8.34	3.24	2.66	28.78	31.17	2.20	1.47	37.74	18.77
Impro(%)		8.85		17.92		8.31		33.09		50.27

[b] FU: Fuel (ml/s); HC: hydrocarbon emission rate (mg/s); MS: mean speed (m/s); QL: queue length (veh); WT: waiting time (s);
SY: synchro plan; RL: reinforcement learning plan; Impro: Improvement.

The proposed research method reduces vehicle delay time by more than 50%, i.e. fuel consumption is reduced by over 8%, emissions of harmful gases are reduced by over 17%, queues of vehicles are reduced by over 33%, while average speeds are increased by more of 8%. In the research [13] TLC in real time was proposed, considering that the management of higher frequency road intersections is primarily carried out by traffic lights, whose inefficient control causes numerous problems, such as long delays for passengers, huge loss of energy and possible traffic accidents. Taking into mind that the existing TLC applies fixed programs without taking real-time traffic into account, the research proposed the application of a deep reinforcement learning (DRL) model, based on Q learning, where a convolutional neural network (CNN) used for state mapping, which is further optimized with several components, namely: dual networks, target networks, dual networks for Q-learning and repetition of the acquired experience. The inspiration to propose a smart real-time TLC system at an intersection is the inclusion of a traffic policeman who takes direct control of an intersection when a fixed traffic control program presents a huge problem. This happens mainly in cases of environmental change in the relative vicinity of the intersection, when there is a change in the input variable (extreme increase or decrease in traffic flow saturation) for which the intersection itself was designed. In the above case, the person observes the actual traffic situation on the intersecting roads and determines the duration of the allowed passing time for each direction using his many years of experience and understanding of the intersection, which is very effective. However, in order to implement such a system, you need "eyes" to observe the road conditions in real time and a "brain" to process it. The general idea is to mimic an experienced operator by controlling the duration signal in each cycle based on information collected from vehicle networks using a Markov decision process (MDP). The system learns a control strategy based on a MDP by trial and error in a DRL model. The proposed model involves optimizing the efficiency of using the intersection by dynamically changing the duration of each traffic light phase through learning based on historical experiences, whereby the duration of the phase should be changed in accordance with the number of vehicles on the road. A deep Q learning network is built to learn the timing strategy of each phase to optimize traffic management, self-updating by continuously receiving states and rewards from the environment. The model is shown in Figure 4. The structure in the traffic light is shown on the left side, where the traffic light first collects information about road traffic, and then processes the data to obtain the road traffic condition and reward, [14, 15]. The traffic light selects an action based on the current state and reward using the deep neural network shown on the right side of Figure 4.

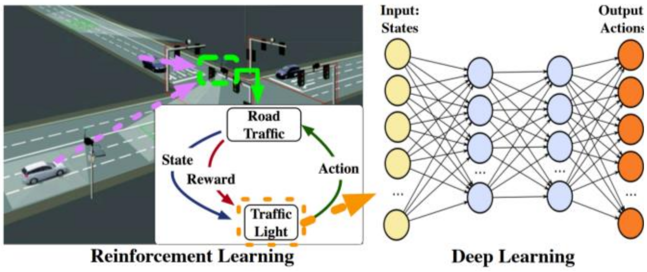

Fig. 4 *Signal plan control based on the "DRL model, based on Q learning" [13]*

In the mentioned model, three elements are dominant: state, action and reward. The condition is defined based on the position and speed of the vehicle at the intersection. The position and speed of the vehicle are determined by dividing the intersection into small squares of the same size whose side length should guarantee that no two vehicles can be kept in the same square, i.e. one whole vehicle can be placed in the grid to reduce the computation (Figure 5 left). In each square, the state value is a vector with two values of positions and velocities, where position is a binary value indicating whether there is a vehicle in the network (Figure 5 right). The action space is defined by the way of updating the duration of each phase in the next cycle. Since the system may become unstable if the change in duration between two cycles is too large, the change step is set to 5s.

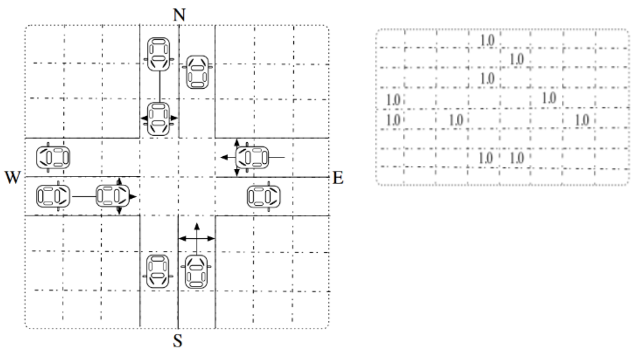

Fig. 5 *The process of matrix formation at the intersection [13]*

Applying a high-dimensional Markov decision process changes the duration of two phases between two adjacent cycles. The phases on the traffic light cycle in sequence, and a yellow signal is required between two adjacent phases to guarantee safety. The role of the reward is to provide feedback to the learning model with confirmation of the performance of previous actions, where it is necessary to properly define the reward that guides the learning process, so that the best action is taken. In the proposed model, the main objective is to increase the efficiency of the intersection and reduce the vehicle waiting time, so the rewards are defined as the change in the cumulative waiting time between two adjacent cycles. The research proposed a CNN for Q value approximation in combination with the most modern techniques, so the whole network is called Double Dueling Deep Q Network (3DQN). The network consists of three convolutional layers and several fully connected layers, where the inputs are small networks, that is, squares that include information about the position and speed of the vehicle. The data is first passed through three convolutional layers, where each convolutional layer includes three parts: convolution, pooling, and activation. A convolutional layer includes multiple filters that have different weights to generate different features in the next layer. The pooling process removes less important information and reduces dimensionality, while leaky ReLU is used in the activation function model due to the speed of convergence that serves to decide how the unit will be activated. The primary CNN based on the current state and trial action selects the most valuable action, and then the current state and action together with the next state and the received reward are stored in memory. The data in the memory is selected by prioritizing the experience playback to generate the mini-series and is used to update the parameters of the primary neural network. The target network is a separate neural network to increase stability during learning, while the 3DQN model with prioritized experience repetition aims to enable an adaptive traffic light that can change the duration of its phases based on different traffic scenarios. The agent chooses the actions that have the maximum Q value and learns to get a high reward by reacting to different traffic scenarios. Basically, the basis of the proposed model is to maximize the defined reward, that is, to reduce the cumulative delay of all vehicles, where the average waiting time is measured by dividing the total waiting time by the number of vehicles in the episode. The evaluation of the model was carried out in SUMO. In the simulation, the conditions were used that the vehicles are 5 m long, and the minimum distance between two vehicles is 2 m, where the vehicles arrive at the intersection by a random process. The average arrival rate of vehicles in each lane is $1/10$ in second. The maximum speed of the vehicle is $13.9\ m/s$, the average acceleration is $1\ m/s^2$, while the deceleration is $4.5\ m/s^2$. The duration of yellow signals is set to 4 seconds. The model is trained in iterations, where one iteration is an hour-long episode. The reward is accumulated in an episode, and the simulation results are averaged over 50 iterations. At the end, the performance of the proposed system was compared with other models, where the first one is the simplest, that is, the duration of the signal plan is fixed and 30 and 40 seconds are set for each phase. Another is a conventional method called Adaptive Traffic Signal Control (ATSC) [16], which proposes Webster's method to estimate the optimal duration of light time based on the saturation of the last cycle. While the third strategy 3DQN was developed through the subject research. The average vehicle waiting time in each episode is calculated and shown in Figure 6, where it is observed that 3DQN outperforms the other strategies.

Looking at the obtained results, it is noted that the average waiting time in signals with a fixed time is always longer than 35s. The proposed model can learn to reduce the waiting time to about 26 s after 1200 iterations from over 35 s, which is at least 25.7% less than the fixed time strategies. ATSC can achieve better performance than the fixed-time strategy, but it uses only a few of the latest cycle information, which cannot represent future traffic well. The performance of DQN is very unstable, which means that a single queue-length neural network cannot accurately capture real traffic information, while the results show that the 3DQN model can obtain the most stable and best performance in average vehicle waiting time among all methods.

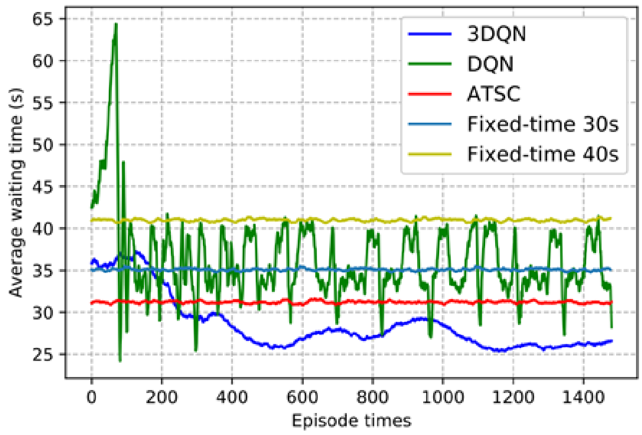

Fig. 6 *Average waiting time during all training episodes [13]*

3 DISCUSSION AND OPEN ISSUE

Although in the last few decades there are a large number of adaptive systems that have been implemented worldwide (SCATS, SCOOT, UTOPIA, OPAC, PRODYN, CRONOS, MOTION, BALANCE, ACA LITE, NWS Voyage, ImFlow, Quic Trac, LA ACST, SyncroGeen, Centracs, KADENCE, SURTRAC and others) and work in real conditions, there are also those that are still at the level of scientific research and laboratory testing for insight into their structure and logic of work as shown in the previous chapter. Each proposed adaptive intersection control model using ML techniques showed a significant improvement in traffic flow at the intersection compared to a fixed signal plan setup. However, like any research, it was considered only in laboratory conditions where not all possible scenarios can be predicted, as in real conditions. One of the shortcomings in the review of the first and second research is the way in which the signal plan is formed after predicting the traffic flow using ML techniques. In the last presented research, a special problem is the formed network that approximates the length of the vehicle of 5 m, which in real cases is not often the case due to the increasing number of small cars, but also delivery vehicles of larger dimensions. Also, one of the shortcomings of the aforementioned research is the implementation in real conditions, where the sensor may stop working to collect information in real conditions, as well as the potential physical inability of the sensor to collect data from a larger number of vehicles in a queue. A special problem is the very expensive placement of cameras and sensors as well as their maintenance, due to the conditions that must be met in collecting information in an extremely short time (the camera must be placed high due to occlusion). In the considered research, the authors did not define the conditions when it is necessary to interrupt the light signaling due to a negligible number of road users.

Searching for the optimal signal plan given the ubiquity of a huge amount of data can be obtained by combining ML to predict the traffic flow at the entrance - exit of the intersection and activating a certain signal plan that supports the required traffic flow saturation. Analyzing historical data collected for 24 hours for as long as possible, which includes the collection of data on the number and speed of vehicles, as well as the consideration of days of the week and weather and temperature conditions that significantly affect the saturation of the traffic flow, would enable the application of ML to predict traffic conditions in the intersection environment on an hourly basis. By considering the mentioned parameters, it is possible to understand patterns of behavior based on time series that occur in traffic under certain conditions. In this way, it would increase the resistance of the model to the possibility of error when managing the signal plan in real conditions, and based on learning through experience, a stable system would be formed. However, like all models, the proposed one would have disadvantages in the form of the need to store a large amount of data.

4 CONCLUSION

In the context of smart traffic, the application of ML techniques is still at an early stage of development. Most of the identified researches are concepts, laboratory experiments or in a very early stage of testing and applications in everyday life are still missing. In the coming years, he expects even more significant progress in the application of ML and DL techniques in controlled light traffic signals at intersections, as the number of IoT devices grows, and the variety and volume of data increases.

This article presents an overview of individual research on ML methods and algorithms for the management of light traffic signals at intersections. However, possible problems in the implementation of the proposed models are shown, challenges and future opportunities are open for research and development of signal management at intersections in order to develop new models.

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UNIVERSITY OF NIS FACULTY OF MECHANICAL ENGINEERING

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til 2023

A RANDOM MOVING, BACKGROUND GEOMETRY AND EXPECTED VALUE

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Abstract

In this paper, we investigate the usage of unknown parts of the elements to reach some distance. This problem can be noticed in making a train track or fishing stick. Our goal is to estimate the expected value of the smallest natural number of the elements. It becomes very interesting problem if we corespond a weight to every element. It can be its price or volume. It leads to the geometrical considerations in multidimensional Euclidean space and a lot of various mathematical functions.

Keywords: *Unit set, random values, expected values*

1 INTRODUCTION

Random walk is the stochastic process formed by successive summation of independent, identically distributed random variables:

$$S_0 = 0, \quad S_n = \sum_{k=1}^{n} X_k,$$

It arises in many areas of science to describe the evolution of certain objects subject to random fluctuations, including random walkers in physics, electric network theory and capital positions in insurance mathematics.

They can be considered in multi-dimensional spaces. Here, we will consider a special one-dimensional random walk which reminds on making a train track on Fig 1 or fishing stick on Fig 2. It was previously considered by H.S. Shultz [1], B. Ćurgus and R.I. Jewetts [3]. We have noticed that it can be used in providing the large class of the functions in our paper [4].

Fig. 1 *Making a train track*

Fig. 2 *Making a fishing rod*

2 PRELIMINARIES

Here, we will expose the basic steps of the procedure.

Procedure. Let

$$a = \{a_k\}_{k\geq 1} \qquad (a_k \in R^+), \tag{1}$$

be a given positive sequence of the weights. They can be real weights, volumes, or prices of the elements. To any random real sequence

$$x = \{x_n\}: \quad x_n \in [0,1] \qquad (\forall n \in N), \tag{2}$$

taken by uniform distribution $U[0,1]$, we can join the finite sequence of weighted partial sums

$$S_{k,m}(a,x) = a_k x_k + a_{k+1}x_{k+1} + \cdots + a_m x_m \ (k \leq m). \tag{3}$$

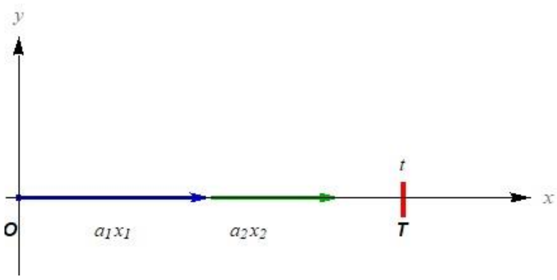


Fig. 3 *Reaching to a given value t by weighted random sticks.*

Take $t > 0$.

Step 1. Take a random number $x_1 \in [0,1]$ and $n = 1$.
Step 2. If $S_{1,n}(a,x) > t$, then memorize the value n and stop the procedure.
Step 3. If $S_{1,n}(a,x) \leq t$, then increase n into $n+1$, take the next random number $x_n \in [0,1]$ and return to Step 2.

Repeat this procedure a lot of times as it is shown on Fig 3.

What is the expected value for n?

We are looking for the expectation:

$$f(t,a) = E\{n \in N: S_{1,n-1}(a,x) \leq t < S_{1,n}(a,x)\}. \qquad (4)$$

Let us denote with $p_m(t)$ the function of a variable t determined by

$$p_m(t) = \mu(P_{m,t}), \qquad (5)$$

where

$$P_{m,t} = \{\, X \in [0,1]^m : S_{1,m}(a,X) \leq t\}, \qquad (6)$$

and μ is the Lebesque measure in R^m. Here, the initial function is $p_0(t) = 1$.

3 GEOMETRICAL INTERPRETATION

Consider the special case of (1) such that

$$a = \{k^s\}_{k \geq 1} \; (s \in R^+ \cup \{0\}). \qquad (7)$$

One-dimensional case

Since $a_1 = 1$, there are 2 cases:
(1.1) For $0 \leq t \leq 1$, it is $P_{1,t} = [0,t]$, $p_1(t) = t$.
(1.2) For $1 \leq t$, it is $P_{1,t} = [0,1]$, $p_1(t) = 1$.

Two-dimensional case

The line $a_1 x_1 + a_2 x_2 = t$ passes through the points $X_1(t/a_1, 0)$ and $X_2(0, t/a_2)$.

(2.1) For $0 \leq t \leq a_1$, the whole segment $X_2 X_1$ belongs to the square $[0,1]^2$ (see Fig.4) Hence $P_{2,t}$ is the interior of triangle $X_2 X_1 O$ and the measure is

$$p_2(t) = \mu(P_{2,t}) = \frac{1}{2} \cdot \frac{t}{a_1} \cdot \frac{t}{a_2}. \qquad (8)$$

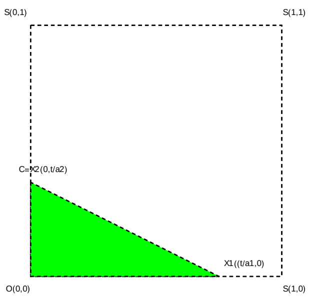
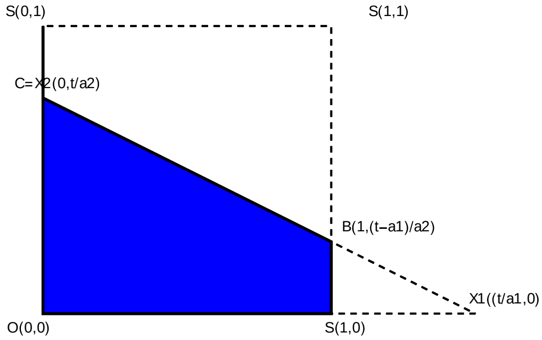


Fig. 4 *Two-dimensional case for t* = 0.75 *and* $a_1 = 1, a_2 = 2$.

(2.2) Let $a_1 < t \leq a_2$. This condition guarantees that the points O(0,0) and *S*(1,1) are from the different sides of the line $a_1 x_1 + a_2 x_2 = t$. We get the trapezoid which area is (see Fig. 5):

$$p_2(t) = \frac{1}{2}\left(\frac{t}{a_2} + \frac{t-a_1}{a_2}\right) = \frac{t^2 - (t-a_1)^2}{2\,a_1 a_2}. \qquad (9)$$



(2.3) For $a_2 < t \leq a_1 + a_2$, the segment $X_1 X_2$ divides the square $[0,1]^2$ into 2 pieces. Hence, like it is shown on the Fig. 6:

$$p_2(t) = \frac{t^2 - (t-a_1)^2 - (t-a_2)^2}{2 a_1 a_2}. \qquad (10)$$

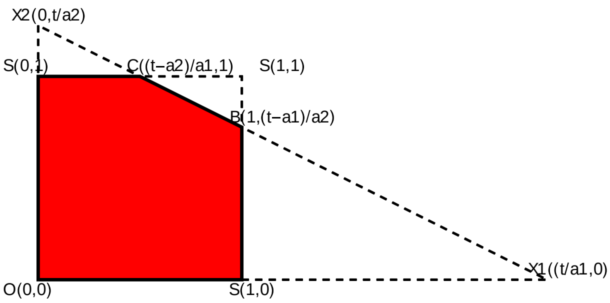


Fig. 6 *Two-dimensional case for t* = 2.5 *and* $a_1 = 1, a_2 = 2$.

(2.4) For $a_1 + a_2 < t$, it is valid

$$a_1 x_1 + a_2 x_2 < a_1 + a_2 < t \qquad (\forall x_1, x_2 \in [0,1]). \qquad (11)$$

Hence $P_{2,t} = [0,1]^2$ and $p_2(t) = 1$.

Three-dimensional case

The plane $a_1 x_1 + a_2 x_2 + a_3 x_3 = t$ passes through the points $X_1(t/a_1, 0, 0)$, $X_2(0, t/a_2, 0)$ and $X_3(0, 0, t/a_3)$.
(3.1) For $0 \leq t \leq a_1$, the solid $X_3 X_2 X_1 O$ belongs to the cube $[0,1]^3$ and its measure is

$$p_3(t) = \frac{1}{6}\frac{t}{a_1}\frac{t}{a_2}\frac{t}{a_3} \qquad (12)$$

(3.2) Let $a_1 < t \leq a_2$. The cutting polygon with the unit cube $[0,1]^3$ determines the solid which has the volume (see Fig. 7)

(13)

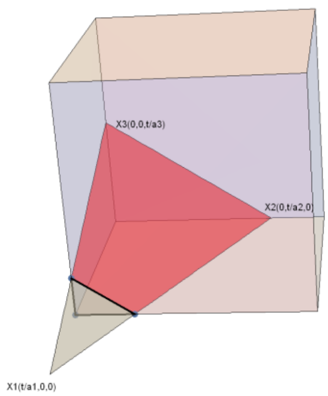


Fig. 7 *Three-dimensional case for* $t = 1.5$ *and* $a_1 = 1, a_2 = 2, a_3 = 3.$

Let us denote by

$$(t)_+ = \begin{cases} t, t > 0, \\ 0, t \le 0, \end{cases} \quad f_+(t) = \begin{cases} f(t), f(t) > 0, \\ 0, \quad f(t) \le 0. \end{cases} \tag{14}$$

Then, all three-dimensional case, we can collect in the next formula for $0 \le t < a_1 + a_2 + a_3$:

$$p_m = \frac{t^3 - \sum_{k=1}^{3}(t-a_k)_+^3 + \sum_{i=1}^{2}\sum_{j=i+1}^{3}(t-a_i-a_j)_+^3}{6a_1a_2a_3} \tag{15}$$

The arbitrary dimensional case

The hyper-plane $a_1x_1 + a_2x_2 + \cdots + a_mx_m = t$ passes through the points $X_1(t/a_1, 0, \ldots, 0)$, $X_2(0, t/a_2, 0, \ldots, 0)$, …, $X_m(0, \ldots, 0, t/a_m)$.

(*m*.1) For $0 \le t \le a_1$, the *m*-dimensional solid is between this hyper-plane and coordinate hyper-planes, so its measure is

$$\mu(X_m \ldots X_1 O) = \frac{t^m}{m! \prod_{j=1}^{m} a_j}. \tag{16}$$

(*m*.2) Let $a_1 \le t \le \sum_{k=1}^{m} a_k$. If the vertex X_k is outside of the unit cube and $S_{\underbrace{0\cdots 01}_{k}0\cdots 0}$ is the nearest vertex of the unit cube, the measure of the small pyramid outside of the unit cube, for $1 \le k \le m$, is

$$\mu\left(X_k S_{\underbrace{0\cdots 01}_{k}0\cdots 0}\right) = \frac{(t-a_k)^m}{m! \prod_{j=1}^{m} a_j}. \tag{17}$$

Since the overlapping of the small pyramids can appear, we must exclude their counting twice. Finally,

$$p_m = \frac{t^m + \sum_{k=1}^{m}(-1)^k \sum_{i_1<i_2<\cdots<i_k}\left(t - \sum_{j=1}^{k} a_{i_j}\right)_+^m}{m! \prod_{j=1}^{m} a_j}.$$

(*m*.3) For $\sum_{k=1}^{m} a_k < t$, it is

$$\sum_{k=1}^{m} a_k x_k < \sum_{k=1}^{m} a_k < t, (\forall x_1, \ldots, x_m \in [0,1]), \tag{19}$$

wherefrom $P_m = [0,1]^m$ and $p_m = 1$.
The probability to exceed $t \in (0,1)$ in one trial, is

$$S_1 = 1\left(\left(1 - p_1(t)\right) - \left(1 - p_0(t)\right)\right) = p_0(t) - p_1(t). \tag{20}$$

If it is not fulfilled, we try to exceed t in the second trial. Here, $a_1x_1 < t$ and $a_1x_1 + a_2x_2 > t$. Feasible set is shown on the Fig 8 and the the second patial sum is

$$f = 1(p_0(t) - p_1(t)) + 2(p_1(t) - p_2(t)). \tag{21}$$

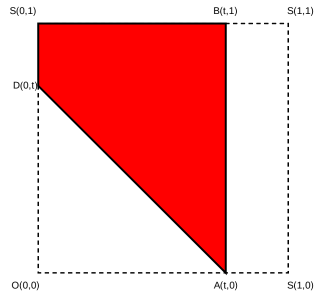


Fig. 8 *Two-dimensional feasible region for* $t = 0.75$ *and* $a_1 = a_2 = 1.$

Let S_n be the event that we exceed t in n-th trial and S_{n-1}^* be event that we did not reach t in $(n-1)$ trials. Obviously, $S_n \cap S_{n-1} = S_{n-1}$, and $P(S_n) = 1 - p_n(t)$. Since

$$P(S_n) = P(S_n \cap S_{n-1}^*) + P(S_n \cap S_{n-1}), \tag{22}$$

we have

$$P(S_n \cap S_{n-1}^*) = \left(1 - p_n(t)\right) - \left(1 - p_{n-1}(t)\right). \tag{23}$$

The expected value for $n = n(t)$ is

$$f(t) = \sum_{n=1}^{\infty} n(p_{n-1}(t) - p_n(t)). \tag{24}$$

If the condition $\lim_{n\to\infty} n\,p_n = 0$ is fulfilled, then

$$f(t, a) = \sum_{n=0}^{\infty} p_n(t). \tag{25}$$

3. ANALYTICAL APPROACH

For a given $n \in N_0$ and $k \in N$, let us denote by

(18)

$$f_n(t; a_k) = \sum_{i=n}^{\infty} \frac{t^i}{i! \prod_{j=k}^{i+k-1} a_j} \quad (t \in [0, a_k]). \tag{26}$$

We accept $f_n(t; a_k) \equiv 0 \quad (t < 0)$.
It is important to note that the functions $f_n(t; a_k)$ are defined for every $t > 0$ according to D'Alambert criteria and the the fact $\min_k \{a_k\} = a_1 > 0$.The next relations are true:

$$f_0(t;a_{k+n}) = f_0^{(n)}(t;a_k)\prod_{i=k}^{k+n-1} a_i, \qquad (27)$$

$$f_0(t;a_{n+1}) = f_n^{(n)}(t;a_1)\prod_{i=1}^{n} a_i \quad (\forall k,n \in N). \qquad (28)$$

The function $f(t;a)$ is known on $(0,a_1)$. It is

$$f(t;a) = f_0(t;a_1), \quad t \in (0,a_1). \qquad (29)$$

For $t \in (a_1,a_2]$, it is valid

$$f(t;a) = 1 + f_{1,+}(t;a_1) - f_{1,+}(t-a_1;a_1). \qquad (30)$$

Including $a_0 = 0$, for $a_1 < t \le a_2$, the previous formula can be written in the following form:

$f(t,a)$= (31)

$$1+\sum_{k=0}^{1}(-1)^k\sum_{0\le i_1<i_2<1} f_{1,+}\left(t-\sum_{j=1}^{k} a_{i_j};a_1\right).$$

Theorem. *If* $a_n < t \le a_{n+1}$ $(n \in N)$, *it is valid*

$$f(t,a) = n+\sum_{k=0}^{n}(-1)^k\sum_{0\le i_1<i_2<\cdots i_k\le k} f_{n,+}\left(t-\sum_{j=1}^{k} a_{i_j};a_1\right). \qquad (32)$$

4. EXAMPLES

In the following examples, the trials were tested *by tge software* Wolfram Mathematica, including the function *RandomReal* with option *WorkingPrecision* with *32* digits when $t = 0(0.2)10$. The number of trials was $N = 1000$.

Example 1. The case $(a_k = 1, \forall k \in N)$ was examined by B. Ćurgus and R.I. Jewetts [1]. They have got

$$f(1) = \sum_{n=1}^{\infty} n\left(\frac{1}{(n-1)!}-\frac{1}{n!}\right) = e \approx 2.718. \qquad (33)$$

Evenmore, we find

$$f(t) = e^t\sum_{k=0}^{\lfloor t\rfloor}\frac{(k-t)^k}{k!\,e^k} \qquad (t>0). \qquad (34)$$

Example 2. The case $(a_k = k^s, \forall k \in N)$ will give the *Laguerre-type exponential function* introduced in [2]:

$$f(t,a) = \sum_{n=1}^{\infty}\frac{t^n}{(n!)^{s+1}} = e_s(t) \quad (0 < t \le 1). \qquad (35)$$

The special case $a_k = k, (\forall k \in N)$, is shown on the Fig. 9. We compare analityc function $e_2(t)$ and graph provided by the experiment.

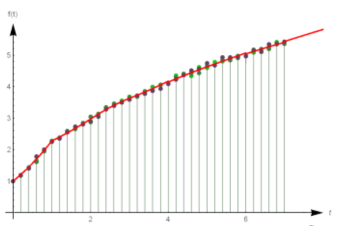


Fig. 9 *The graph of* $f(t;a)$ *for* $a_k = k\ (k \in N)$

Example 3. The q-Pochhammer symbol is given by

$$(q;q)_0 = 1, \quad (q;q)_n = \prod_{k=1}^{n}(1-q^k) \qquad (n \in N). \qquad (36)$$

The case $a_k = 1-q^k$ $(0 < q < 1; k \in N)$ is shown on the Fig. 10. It is leading to a Laguerre type q-exponential function (see [4]):

$$e_{1,q}(t) = \sum_{n=1}^{\infty}\frac{t^n}{n!\,(q;q)_n} \qquad (0 < t \le 1-q). \qquad (37)$$

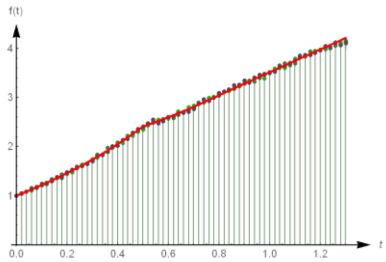


Fig. 10 *The graph of the function* $f(t;a)$ *for* $a_k = 1-q^k$ $(q = 0.5)$

5. CONCLUSIONS

The geometrical and analytical approaches, applied on a random number problem, have shown that we can get a lot of different, known functions or their generalizations which express the expected value. A lot of different cases wait to be examined, such as with given decreasing sequences or sequences which are not monotonous.

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THE IMPACT OF CITY LOGISTICS ON TRAFFIC AND THE ENVIRONMENT

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Abstract

For the purpose of sustainability of urban areas and efficient realization of distribution of goods in cities, city logistics should be a subject of planning and creation of city policy, because logistics activities, at the same time, represent a threat to the processes that inexorably strive to maintain. City logistics needs to find a balance between the efficient distribution of goods, i.e. meeting the existential needs of city dwellers, and the impact of the same efficient distribution of goods on the flow of traffic, as well as on the effects that affect the environment.

This paper will present research on the impact of means of transport, which participate in the distribution of goods, both on the flow of traffic, and on their impact on the environment, during the unloading of goods in a retail store, in a certain period of time.

Keywords: *City logistics, Environment.*

1 INTRODUCTION

The high concentration of people in cities and rich content of economic and social activities are constantly increasing, what shows us complexity of satisfying all needs. We are all living in a time when cities and their quality depends on the supply and variety of the assortment of goods in retail stores. However, in order to achieve a high level of diversity of product range, or selection of goods, both basic to life, and those that give and raise the level of quality of life in cities, and that can be purchased only in the cities, there must be a well-organized logistics supply of retail goods, which, goods creates a direct relationship with the customer, or placed at the disposal of the city's population. Logistics is very important for the functioning of cities, and has an important impact on the quality of life, mobility of the population and the sustainability of cities. Efficient distribution of goods is essential for life and the survival of people in cities. The main characteristic of the distribution of goods in cities is reflected in the fact that the delivery of goods small scale is quite frequent or common. Spatial distribution transport distance of goods in road transport is such that the largest number of transport tasks up to 5 km, and even 51% of the total volume of transported goods is realized at 10 km. [1]

In addition, as the distribution of goods in cities raises the level of competitiveness of urban areas, it has a positive effect on employment growth, which is directly related to the distribution of goods, performance of the transport of goods, and indirectly on retail stores and etc. However, in addition to the above distribution of goods in urban areas has negative characteristics to the traffic and the environment. Due to the high frequency, or frequency in the distribution of goods, delivery vehicles have a huge impact on the capacity of roads, especially during the unloading of goods in retail stores, as during the unloading of goods, delivery vehicles are generally parked on city roads. In addition, cause the emission of harmful gases, soot particles, creating a lot of noise, both on landing, and during movement. They have a negative impact on the environment in cities.

The aim of sustainable urban environment and the effective implementation of the distribution of goods in cities. City logistics should be subject to planning and policy of the city, because the logistics activities, also represent a threat to the processes that are inexorably harder to maintain. City logistics needs to find a balance between effective distribution of goods or satisfying basic needs of residents in the cities, and the impact of same on the efficient distribution of goods, as well as the influences that affect the environment.

This paper will be presented to survey the impact of transport equipment, which participate in the distribution of goods, both in traffic and on their impact on the environment, during the unloading of goods in the retail store, in a certain period of time.

2 THE CONCEPT OF SUSTAINABLE DEVELOPMENT

Logistics activities have recently been focused exclusively on reducing the cost of the flow of goods in the supply chain, as well as improving the quality of logistics services, primarily to reduce delivery times, increased flexibility of delivery, reliability of delivery, readiness to deliver supplies correctness etc.

The concept of sustainable development has emerged as a result of large-scale climate change, global warming, the emergence of greenhouse gases and etc. These negative changes create or have a major impact on them and their formation and transport of goods and passengers. The high concentration of people in urban areas, leading to a great need, both for their own movement, travel by car or public transport, and for meeting the basic needs for food, drink and the like. City authorities have mainly focused on solving problems traditionally associated with public transport, the use of passenger cars, other forms of passenger transport, while the transport and delivery of goods largely ignored. These vehicles have a major negative impact on both the climate change and on the scope and structure of traffic.

The concept of sustainable development refers primarily to meet current needs without compromising the ability to satisfy the needs of future generations. To make the concept of sustainable development was defined by the applicable term triple bottom line, which emphasizes that economic, social and environmental reasons are equally important in decision making. [2]. This term is known as the triple P *(People, Profit, Planet),* which means that the logistic activities that are planned, controlled and carried out during the flow of material goods equally focused, or both are important factors, in addition to the cost factor that occur during the running of goods and factors of meeting the needs of people, and a factor of environmental stredine.

2.1. City logistics impact on sustainable development

The supply of people with basic necessities, as well as those associated, in terms of the diversity of the assortment of goods in cities, causing a series of negative and unsustainable activities. The functioning of these negative activity, or the formation of non-viable activity refers primarily to the population, the profit which is realized during implementation of various orders and their impact on the planet, as the impact on the environment.

The negative impact on the population, which is made by vans refers primarily to the effects of exhaust gases, which adversely affect the health of people and can cause a variety of diseases. In addition to the presence of exhaust gases and noise, generated by these vehicles, as well as various vibrations that create discomfort among the population. The presence of commercial vehicles in the total volume of traffic, also has a negative impact on the population, because it increases the risk of traffic accidents. Violation of the quality of life of residents, in terms of loss of green areas, and the loss of attractiveness of the area for transport and logistics infrastructure development. When one looks at the impact of city logistics at a profit, or economic viability, there are two sides. One page refers primarily to profit from the flow of material goods. However, goods which are located in retail stores must be competitive in the market, both quality and price. Great impact on the price of goods that are located in retail outlets, has primarily transport. When it comes to transport, and in particular the delivery of goods in retail stores, the main characteristic of these transport tasks, is that very frequently, and frequent delivery of goods in retail stores. In addition, the vans that carry out freight delivery, or servicing goods retail stores, their cargo space is generally under-utilized, which by volume, which, according to the loading permitted weight of the vehicle. This creates a waste of resources, and thus additional costs that affect profit. In addition, these vehicles to transport completed its task must participate in traffic, and thus create added congestion and reduce accessibility in cities because of its dynamic driving characteristics of the vehicle, causing an additional impact on profit. On that basis, brings into question the reliability and accuracy of delivery, which is directly related to quality of service, which also has a direct impact on profit alone.

The impact of the delivery of transport, in addition to the impact on the population and economic viability, or profit, has an impact on the environment. The negative impact is mainly reflected due to emissions of greenhouse gases, which cause these vehicles. When it comes to emission urban transport is among the causes of climate change. Also, it is important to note that these vehicles are currently using fuels that are fossil or non-renewable natural resources, which according to this criterion could be considered as unsustainable development. In addition, the maintenance of these vehicles includes the replacement of tires, motor oil and other materials whose disposal has a direct impact on the environment, and whose influence it one of the unsustainable are twofold.

3 DELIVERY OF GOODS OBSERVED RETAIL STORE

Delivery of goods retail stores is one of the logistics of everyday activities that make life a lot of people in the cities richer, and provide a greater choice of various item, how the basics of life, and those accompanying. The importance of this activity, ie city logistics, is given only when the required items or goods are not made available to customers in the retail store. Only then is questioned how the city logistics functions in various cities, in circumstances takes place, what factors influence its development and delivery of goods retail stores. However, their city logistics operation, and striving to meet customer needs, creating negative consequences, affecting not to those users whose needs are relentlessly striving to meet.

Considered one retail store in a period of seven days. Based on the counting of deliveries per day observed deliveries given in Figure 1. In terms of deliveries, each delivery is realized in an average time period of 20 minutes. Very important to note that the retail store has only one server for receipt of goods, which means that if you are in the same time interval the appearance of two or three vehicles, unloading will be done only for one vehicle, while the rest one or two cars are waiting to unload. Also, it is very important to note that while the goods are unloaded from the vehicle or vehicles while waiting to unload goods retailer, these vehicles are stationed or parked on the carriageway. Lane where the vehicles are stationed during unloading or while waiting at the unloading has two lanes in one direction. It means that the capacity of the carriageway is reduced by 50 [%] in the time interval when it is unloaded, or waiting for the delivery vehicle to the unloading of the goods. However, when it comes to capacity, the vehicles in addition to this part of the street network, the real problem overall street network.

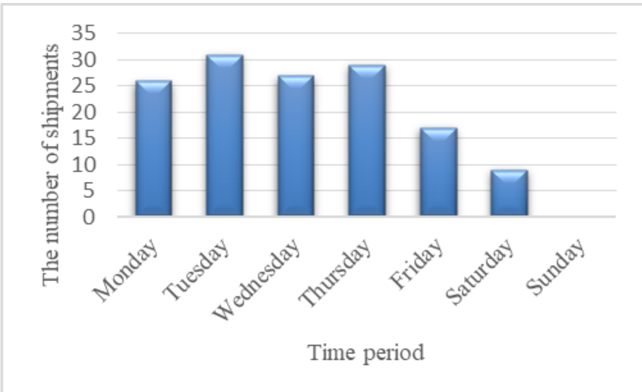

Fig. 1 The number of shipments of goods observed retailer

During the research, observed retail store receives goods or delivery till 2 p.m. every day. Also, it was noted during the study that the maximum number of delivery vehicles that occurs on unloading at the same time interval is three vans, and a delivery vehicle is unloaded, and two vans waiting to unload, which means that on carriageway are three parked vehicles.

3.1. The impact of commercial vehicles on the environment

Delivery vehicles used for carrying out these activities, belong to a heterogeneous fleet, or in structure, can be classified as light trucks. Light-duty vehicles have characteristics which give them this type of transport tasks, because they have good maneuverability, and in contrast to heavy goods vehicles much easier to find a place to stop and parking while unloading goods in a retail store. However, it is very important to note the basic difference between them, but this is primarily related to capacity, as well as the relationship between the weight of goods transported and power of vehicles that transport goods. So in terms of environment, the occupation of space, the capacity of roads and air pollution, light trucks don't have advantages compared to heavy-duty vehicles. The main reason is that the use of light-duty vehicles generates a higher number of deliveries, which is the feature of the delivery transport or distribution of goods. This promotes higher frequency of the vehicle in carrying out its transport assignments.

When it comes to light commercial vehicles used in the distribution of retail goods, we can not avoid the impact on the environment. Vehicles used for delivering goods to retailer observed are mostly older than 15 years. Refurbishing of fleet used for delivery of goods in cities, is slower from refurbishing of fleet used in long-distance transport of goods. The main reason for this is that distribution of goods mainly deals with smaller companies, that in order to reduce the cost competitiveness use older vehicles.

Based of study [3], light trucks emit gases, and these are primarily CO, and carbon monoxide, volatile hydrocarbons NMVOC, nitrogen oxide NO_x, particulate matter PM, nitrous oxide N_2O, ammonia NH_3, as well as other substances which have a detrimental effect on the environment and the inhabitants. Of course, these are vehicles with a drive unit with internal combustion engine, which is fueled with diesel fuel. Based on the research [3], Table 1 shows the contamination of the light-duty vehicles which is emited while discharging the goods to the retailer. It was the winter period when unloading of goods to the retailer was observed. It is assumed that the main reason of the work of the vehicle during unloading was heating the cab driver, and ensuring pleasant working conditions.

Table 1 Emissions from a delivery vehicle [g/kg fuel]

Exhaust gases of a vehicle	**[g/kg fuel]**
CO	11
NMVOC	1,75
NOx	15
PM	2,8
N2O	0,069
NH3	0,014
In total	30,633

Based on this we can conclude that a delivery vehicle produces 30,633 g / kg fuel emissions during a delivery of goods to retailer. This is the average value, which is based on our research [3]. Various standards and regulations prescribe limits for exhaust emissions of motor vehicles, or in the Republic of Serbia has no regulations that limit the vehicles can be used for purposes of city logistics and transport tasks to perform in cities.

Based on the research, by using regression analysis for the observed retail store, a model of pollution by exhaust gases from commercial vehicles could be made, where the number of deliveries during the day is independent variable and the dependent variable is impact of commercial vehicles on the environment based on exhaust emissions of these vehicles. Data is the linear equation (1) that represents the relationship between these two variables.

$$y = -109{,}4x + 1092{,}6x \quad (1)$$

Based on regression analysis, we can conclude that if increase the number of deliveries of goods to retailer, it will increase pollution produced by delivery vehicles, and their emissions of gases. That will negatively affect both the population and the environment, as well as quality of life.

3.2. The impact of commercial vehicles on the road capacity

When delivering goods to retailer, both for unloading, vans use traffic lane for parking, both for unload, so also for waiting to unload. Carriageway consists of two traffic lanes for vehicles moving in that direction. So that during the performance of discharging the goods, or the mode of delivery vehicles to the unloading, the flow of traffic uses only one traffic lane, wherein the lane capacity is reduced by 50 [%]. Very important to note is that retail facility is receiving deliveries by commercial vehicles till 2 p.m. So vans, when carrying out its transport assignments or during unloading or waiting for unloading, they park in a traffic lane in the morning peak hour.

Retail has one server for receipt of goods, where the average time of delivery 20 minutes. In one hour of receipt of the goods server can serve a maximum of three vans. Based on research, there was a maximum of three vans in one time interval. However, the capacity of the carriageway, in that time interval, is reduced to a single lane for a time period of 1 h. In this situation the third delivery vehicle will wait 40 minutes to unload, and will spend 20 minutes for unloading. It means that the vehicle will be placed 1 h on that lane.

With regard to the capacity of the lanes, the lanes on the maximum capacity is 3000 [PA / h / direction], on the basis of a HCM-2000. With taken into consideration all constraints, the maximum capacity of a traffic lane in 1500 [PA / h / line]. This is about the maximum capacity, which means that on this road does not appear such a large number of vehicles, because it occurs more than 1500 [PA / h / direction] in a situation when the delivery vehicle is unloading the goods, or waiting to unload, transport could not take place.
However, in the future, considering that the degree of motorization increases, special care must be taken and given to these situations.

Featured depending on the model between the number of deliveries, and time spent on lane. Based on regression analysis, a model where the independent variables are deliveries of goods to retailer, a dependent variable is the time a vehicle spends on the basis of the time of unloading on the carriageway. Delivery truck waiting to unload is not taken into account, because if a delivery van is waiting for unloading it means that the other vehicle which had come before it, is unloading.

The main reason for this observation is because the vehicle that is being unloaded and the vehicle waiting to unload, are parked in the same lane. So to have the same impact on capacity, regardless, whether they are in the lane of one or more of parked vans. Data is the linear equation (2) that represents the relationship between these two variables.

$$y = -71{,}429x + 713{,}33 \quad (2)$$

Based on this model, it can be concluded that the higher number of deliveries means the greater number of time occupancy of lane, which in this case is represented in minutes. The higher occupancy of lane, expressed in minutes, on the other side brings less capacity lane.

4. CONCLUSION

Based on the research it can be concluded that it is very difficult to find a balance between meeting the basic needs of the population, and their quality of life, in terms of environmental protection, reduction of noise, vibration and the like. Reducing the travel time is the need of residents in cities. It is reflected in the accessibility and capacity of roads. Based on research and mathematical models, it can be concluded that the higher number of deliveries, will increase the level of pollution caused by vans carrying out its transport tasks.

On the roads and at the intersections, and the entire street network in the city. Vans must use the road network for completing their delivery tasks. The main measures for the sustainability of city logistics, that is, finding a balance between two already mentioned components that affect their interests poor on the other, are:

- Higher commitment to city logistics to solve its problems and optimize the entire process, with the aim of maximizing the effectiveness and efficiency, taking into account optimizing costs, and meet the needs of residents and the environment as a factor that needs attention in the planning and implementation of the current burdens;

- Avoiding peak period for the implementation of transport tasks by delivery vehicles in cities, which would be the result of previous traffic counts and determined traffic volumes during the day, and based on that, determine the time periods during the day when the delivery transport should be realized in the cities;

- Do not overwrite city logistics transport policy from other cities because every city has a different traffic volume, traffic structure, as well as the different supply and demand, but policy planning city logistics in the particular case, with the input data of observed city;

- Greater involvement of the city, in terms of paying attention to the overall traffic planning, as well as the adoption of the strategy by the city for city logistics, its planning, implementation, sustainability, with regard to the adoption of the law on the restriction of the number of delivery of a particular part of the city in a week, and in view of the limitations of conditions to be met by vans to establish regular distribution of goods in the city;

- The tendency of greater utilization of space of delivery vehicles, realization of distribution of goods by using vehicles with higher capacity, which in the existing state of impact on reducing frequency of deliveries to retailer would significantly have an impact on the reduction of environmental pollution by emissions;

- Using a delivery vehicle for the realization of the distribution of goods in cities, whose age does not exceed one year, and whose emissions corresponds strictest emission standards, with the aim of crossing vans with fuel to electricity.

In the future, great attention must be paid to city logistics, work on its optimization, weigh no spillage of resources, but their savings as well as the planning of city logistics, making development plans for a specific time period.

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