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FACULTY OF MECHANICAL ENGINEERING
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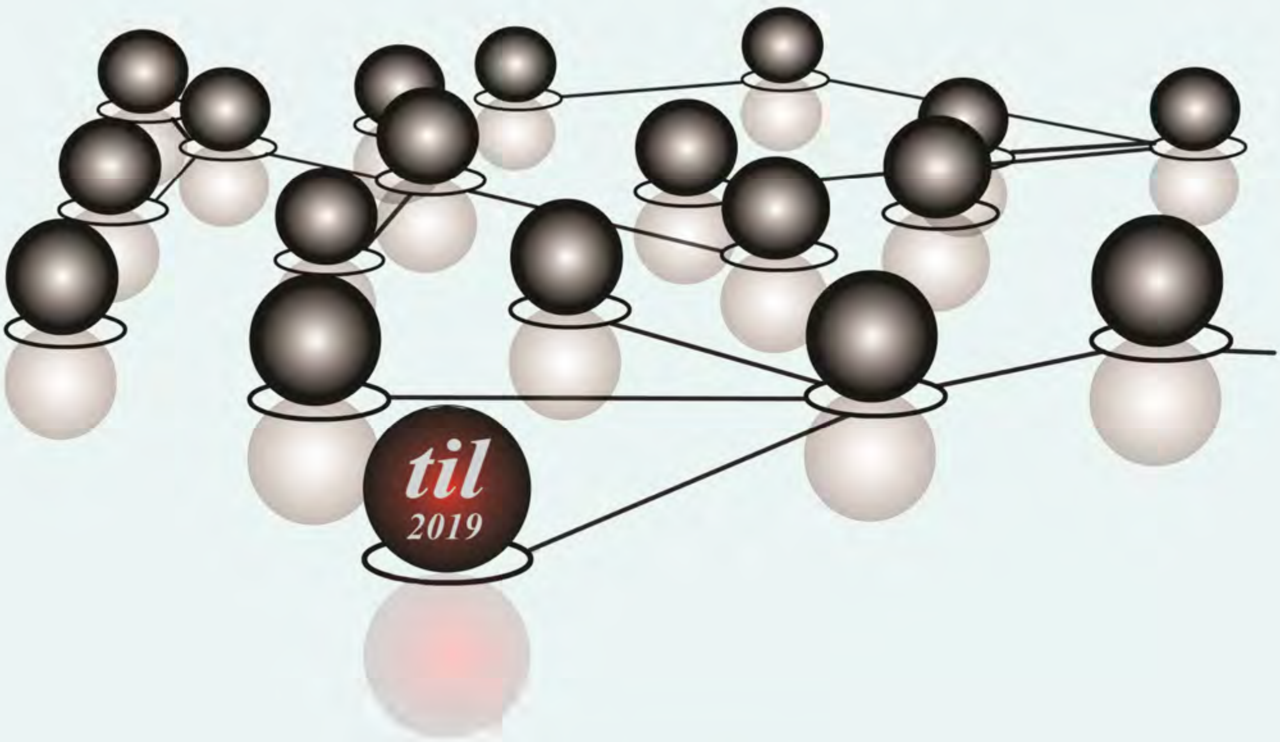

Niš, Serbia 6 December 2019

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TRANSPORT AND LOGISTICS

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Prof. Dr. Dragoslav Janošević

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Jovan Pavlović
Predrag Milić
Aleksandar Stanković
Jelena Mihajlović

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CONTENTS

FOREWORD

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.

Assessing the importance of the education and development of transport and logistics in the Republic of Serbia and Southeast Europe, a new teaching profile Transport Engineering and Logistics was introduced and began to develop in 2002 at the Faculty of Mechanical Engineering, University of Niš, through the TEMPUS programme.

The Department of Transport Engineering and Logistics of the Faculty of Mechanical Engineering, University of Niš, has thus far organized six scientific events under the title of Transport and Logistics with the aim of presenting the research results and plans in the field of transport and logistics. The first event was held in 2004, as a symposium within the TEMPUS project, while the last was held in the form of a scientific conference in 2017.

This year, **the Seventh International Scientific Conference Transport and Logistics – TIL 2019** is being held at the Faculty of Mechanical Engineering in Niš. The conference is characterized by the participation of researchers from universities, faculties, institutes and various organizations from Germany, Croatia, Bosnia and Herzegovina, North Macedonia, United Kingdom, Libya and Serbia. The scientific and professional papers of the Conference participants contained in the Conference Proceedings are divided into four thematic areas: smart logistics systems, intelligent and innovative material handling equipment and transportation systems, traffic engineering, urban mobility and city logistics and constructions and design engineering.

Among other things, the Conference highlights smart logistics systems networked with the concepts of industry 4.0, smart cities, urban mobility, environmental protection and sustainable development.

The general conclusion of the Conference is that increasingly complex and uncertain transport and logistics issues are being addressed through the development of new multidisciplinary methods and algorithms using modern transport systems and information technologies.

Prof. Dr. Dragoslav Janošević

INTRODUCTION

UNIVERSITY OF NIS FACULTY OF MECHANICAL ENGINEERING

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CHALLENGES OF ASSISTIVE TECHNOLOGIES IMPLEMENTATION INTO INDUSTRY 4.0: A REVIEW

Marko PERIŠA[1]
Dragan PERAKOVIĆ[1]
Petra ZORIĆ[1]

[1)] *University of Zagreb, Faculty of Transport and Traffic Sciences, Department of Information and Communication Traffic, Vukelićeva 4, 10000 Zagreb, Croatia*

Abstract

The concept of Industry 4.0 is characterized by the era of digitization. Business models, environment, production systems, products and services interconnect in the Industry 4.0 environment. The quality of changes in production processes reflects the fact that the entire production process is managed and supervised in an integrated way that is combined and flexible. The current industry brings a new accepted point of view in the processes of digital technology applications in the fields of logistics and manufacturing. Most of its application relates to automation processes where human work and modern information and communication solutions and services are replaced. For this reason, the concept of Industry 5.0 has appeared recently. The current research areas of Industry 4.0 and Industry 5.0 are not sufficiently focused on the possibilities of developing and applying forms of assistive technologies and services in terms of inclusion of persons with disabilities in work processes. Assistive technologies contribute to raising the quality of life of person with disabilities. This paper aims to represent the extent to which assistive technologies are used in the concepts of Industry 4.0 and Industry 5.0 and what are the challenges of implementation of such technologies. The paper will also represent the opportunities that person with disabilities can do with the help of assistive technologies in smart factories.

Key words: *Industry 5.0, Smart Workplace, Person with Disabilities, IT Services*

1 INTRODUCTION

This paper presents the findings of research in the field of assistive technologies (AT) application in persons with disabilities and persons with communication skills working environment. Furthermore, papers about using AT in the working environment of the person with disabilities and the fields of Industry 4.0 (I4.0) and Industry 5.0 (I5.0) are analyzed. In countries with low and medium economic development, 5-15% of people have access to AT [1]. Also, there is a problem of educating staff who should educate persons with disabilities about the possibilities and ways of using AT. According to the [1], the Convention on the Rights of Persons with Disabilities (Articles 20 and 26), World Health Assembly resolution WHA58.23 and the United Nations Standard Rules on the Equalization of Opportunities for Persons with Disabilities emphasize the importance of AT. Their application in all areas of persons with disabilities life would increase the degree of mobility but also the quality of life. In this paper, the aim is to represent the features of I4.0 and I5.0 with the possibility of AT implementation as a technology that would provide a more accessible work environment for person with disabilities. The field of Society 5.0 represents the basis for the involvement of all users in work processes, and thus the persons with disabilities are also elaborated.

2 CHARACTERISTICS OF INDUSTRIES 4.0 AND 5.0

With the development of the industrial revolution throughout history, the environment in which the worker was located has changed greatly, adapting to the needs of the market as well as production. The technologies represented by the first industrial generation to date have experienced great expansion. The application of information and communication technology (ICT) started from the third generation of industrial development until today [2].

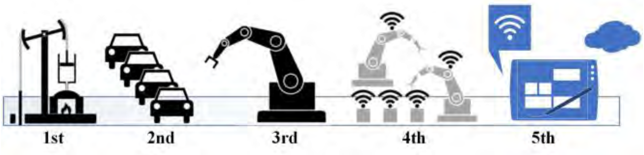

Fig. 1 *Five generations of industry development*

Industrial development throughout history is shown in Figure 1. The first generation of industrial development (1780-1860) in technological terms was based on steam power and machine tools. These technologies have enabled the production of several complex and expensive products tailored to the needs of end users. The second generation (1870-1950) represents the technological generation in which electricity is introduced into production processes and the process of mass production begins. The third generation (1970-2000) gradually introduced information and communication (IC) technologies and services into industrial processes. For the first time in the manufacturing process, the notion of automation is emerging, resulting in a new paradigm in the world of industry, mass customization. The fourth generation of industrial development (2000-present) is called I4.0. It is characterized by a high representation of ICT, mostly in the digitization process, and the use of sensor technology. The most common ICT is Internet of Things (IoT) that allows the connection of things from environment (machines, tools, workers, customers, products and other objects), all with the aim of delivering real-time information.

With its characteristics, IoT enables the development of a new paradigm in the production process, personalized production. This paradigm fulfills the customer's ongoing desire to participate in the design phase of products or services. Technologies represented in the I4.0 paradigm are shown in Figure 2.

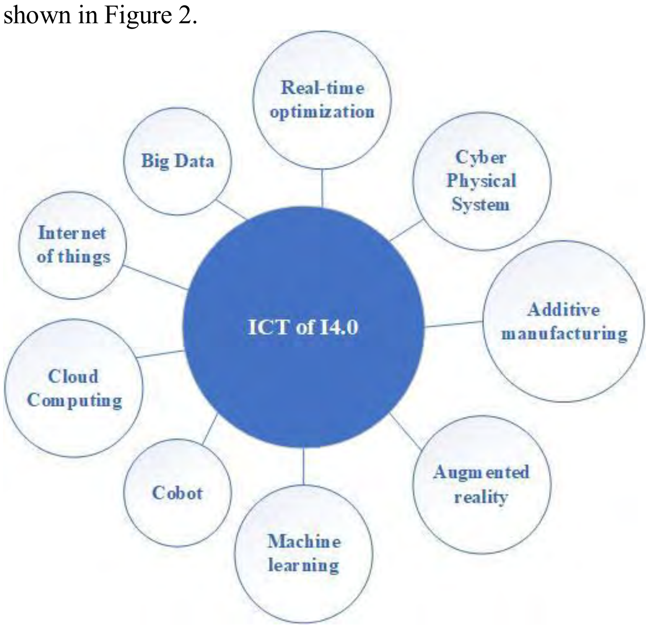

***Fig. 2** ICT representations in the field of I4.0*

The basic features of I4.0 are shown in Table 1 [2]. The table shows the basic requirements in the digital transformation process in I4.0.

Table 1 Features and requirements related to the I4.0

Main Features	Main requirements to face digital transformation
Interoperability	Standardization
Virtualization	Work organization
Decentralization of decision making	Availability of products
Real-time capability	New Business Models
Service orientation	Know-how protections
Modularity	Availability of skilled workers
	Research investment
	Professional development
	Legal frameworks

I5.0 represents the future, an upcoming technology in manufacturing and industry processes. The concept of I5.0 focuses on greater human involvement, personalization of services and greater interaction with robots. Robots will no longer have independent roles in the automation process, but their role will be transhipped into a superior human partner depending on the use case [3]. In this way, it will be presented as a new generation of robots, called cobots. Cobots will be aware of the human presence, will have the functionality to quickly learn and understand the set goals and tasks. It will also take care of how all relevant safety criteria and processes related to work risks are implemented. A person in the presence of a cobot will have a different experience of working in a work environment, all to satisfy the quality of work.

3 A LITERATURE REVIEW IN THE FIELD OF ASSISTIVE TECHNOLOGY DEVELOPMENT

With the development of I4.0 and future trends such as I5.0, the concept of Society 5.0 is emerging. The term Society 5.0 first appeared in Japan in parallel with the development of I4.0. It is focused on a human-centered social environment that balances economic progress by solving social problems. Society 5.0 is a system that highly integrates cyber and physical space [4]. In such an environment, models of AT can be used to increase the involvement of person with disabilities in work processes.

3.1 Assistive technology

AT is based on the application of ICT to overcome the everyday needs and actively engage in the daily activities of person with disabilities and elderly [5]. AT is divided into devices and services:

- AT Device - Any item, piece of equipment or product system, whether acquired commercially off the shelf, modified, or customized, that is used to increase, maintain, or improve the functional capabilities of person with disabilities.
- AT Services - Any service that directly assists a person with a disability in the selection, acquisition, and use of an AT device.

AT devices are available in categories to address functional capabilities of person with disabilities. These categories include, but are not limited to [6]:

- Academic and Learning Aids: Electronic and non-electronic aids such as calculators, spell checkers, portable word processors, and computer-based software solutions that are used by person who has difficulty achieving in the educational curriculum.
- Aids for Daily Living: Self-help aids for use in activities such as eating, bathing, cooking, dressing, toileting, and home maintenance.
- Assistive Listening Devices and Environmental Aids: Electronic and non-electronic aids such as amplification devices, closed captioning systems, and environmental alert systems that assist person who are hard of hearing or deaf with accessing information that is typically presented through an auditory modality.
- Augmentative Communication: Electronic and non-electronic devices and software solutions that provide a means for expressive and receptive communication for person with limited speech and language
- Computer Access and Instruction: Input and output devices, alternative access aids, modified or alternative keyboards, switches, special software, and other devices and software solutions that enable person with a disabilities.

- Environmental Control: Electronic and non-electronic aids such as switches, environmental control units, and adapted appliances that are used by person with physical disabilities to increase their independence in all type of environment.
- Mobility Aids: Electronic and non-electronic aids such as wheelchairs (manual and electronic), walkers, scooters that are used to increase personal mobility.
- Pre-vocational and Vocational Aids: Electronic and non-electronic aids such as picture-based task analysis sheets, adapted knobs, and adapted timers and watches that are used to assist person in completing pre-vocational and vocational tasks.
- Recreation and Leisure Aids: Electronic and non-electronic aids such as adapted books, switch adapted toys, and leisure computer-based software applications that are used by person with disabilities to increase participation and independence in recreation and leisure activities.
- Seating and Positioning: Adaptive seating systems and positioning devices that provide person with optimal positioning to enhance participation.
- Visual Aids: Electronic and non-electronic aids such as magnifiers, talking calculators, Braille writers, adapted tape players, screen reading software applications for the computer, and Braille note-taking devices that assist person with visual impairments or blindness in accessing and producing information that is typically present in a visual (print) modality.
- Working environment: A working environment in which a person with disabilities can exercise the right to work and equal opportunity to participate in society.

3.2 Possibilities of assistive technologies application in Society 5.0

With the development of AT and the new concepts I4.0, I5.0 and Society 5.0, it is possible to increase the quality of life of person with disabilities and person with reduced and difficult communication skills [7]. A sustainable ecosystem is a starting point in integrating AT and the inclusion of person with disabilities in the work environment of a smart factory and industry in general. Also important is the integration of science, technology and innovation into the field of Society 5.0 from the perspective of a sustainable ecosystem [4], [8], [9].

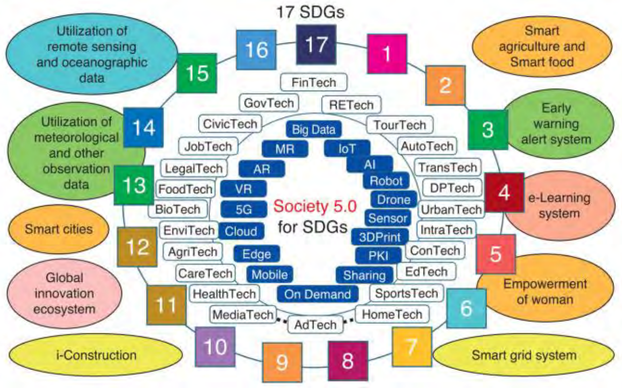

Fig. 3 Key points of the sustainability for concept Society 5.0 [10]

In September 2015, the United Nations adopted the 2030 Agenda for Sustainable Development with Sustainable Development Goals (SDGs) as its core. The aim is to make a comprehensive system in which all nations work together in a sustainable world that hopes to make economic development and address social issues. In such an environment, greater use of AT is possible, and thus greater involvement of persons with disabilities in work processes. Figure 3 shows the concept of Society 5.0 and key technologies with 17 SDGs.
The key ICT in the development of Society 5.0 and the possible integration of AT into work processes are [11]:

- Application Program Interface (API),
- Machine learning,
- IoT,
- Big data analytics,
- Distributed ledger technology (DLT),
- Smart contracts,
- Cloud computing,
- Cryptography and
- Biometrics.

Quality of life (QoL) is an important aspect of Society 5.0. ICT have the task to raise the level of customer satisfaction in a smart factory or industry environment.

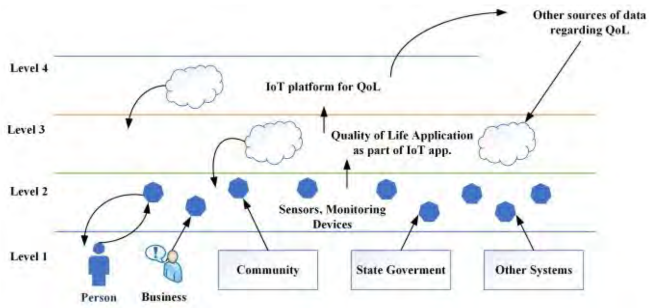

Fig. 4 The structure of the IoT platform for QoL [7]

The structure of the IoT platform to achieve a higher quality of life, i.e. the possible development of services based on modern ICT is shown in Figure 4. The needs of present and future habitans are fast changing based on the QoL approach. On the other side, fostering the industrial revolution to I4.0 and Industry 5.0 is not enough. Now is necessary to integrate these concepts into one integrated QoL/Society 5.0 concept. The interrelationship between digitalization aims and sustainable development aims, contained in concepts I4.0 and Society 5.0. have been investigated by the authors on the example of the Russian industry [12]. Many problems have been identified in adapting the Russian industry to changes in new approaches to work and in the processes of I4.0 and Society 5.0.

The need to define a comprehensive methodology on the impacts of global digitalization of the economy and society as well as a methodology for ensuring competitiveness and sustainable development is established.
Everything mentioned in this chapter can serve as a starting point in designing new services based on AT models, all with the aim of greater integration of person with disabilities into the community.

4 CHALLENGES OF ASSISTIVE TECHNOLOGIES APPLICATION IN I4.0

The field of I4.0 is a major step forward in the process of automating many businesses, all to improve the success of new business models. By creating a new I5.0 environment, work processes in industry and manufacturing are changing. The worker (man) becomes a central spot in the work processes and environment of the industry. Persons with disabilities, under Council Directive 2000/78 / EU and the Employment Guidelines, need to be guaranteed employment opportunities and equal opportunity in involving the wider community.

AT and their development can enable greater inclusion of persons with disabilities in the work processes of I4.0 and I5.0 environments. It is described in the book The Promise of Assistive Technology to Enhance Activity and Work Participation [13]. The book outlines the potential impact of AT on the working environment of persons with disabilities in the US.

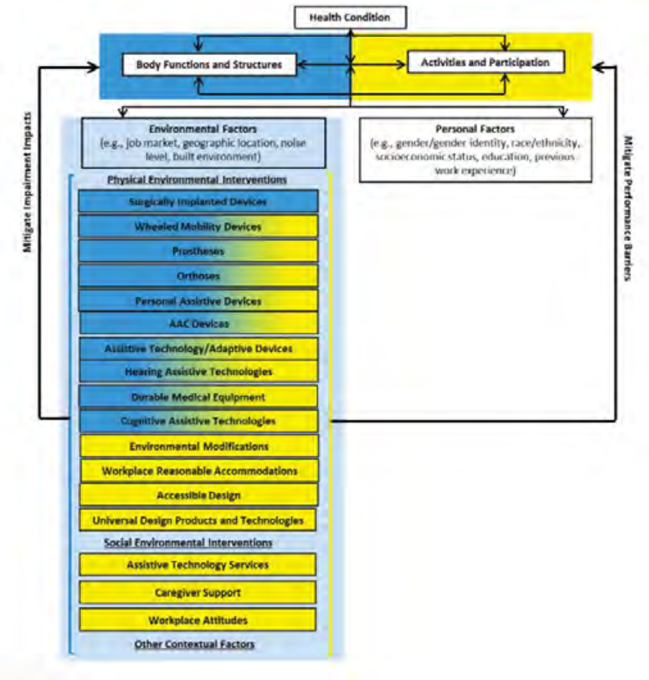

Fig. 5 *Environmental facilitators framework* [13]

The environmental facilitators framework illustrated in Figure 5 is a conceptual model showing potential relationships. It builds on the International Classification of Functioning, Disability and Health - ICF to name specific environmental interventions and the pathways along which those interventions can act either to mitigate the impact of impairment by restoring or replacing relevant body structure and/or function or to enhance activities and participation by mitigating performance barriers. The former interventions target organ system impairment(s), while the latter target contextual factors.

As shown in Figure 5, environmental factors include physical environmental interventions, social environmental interventions, and other contextual factors (light blue box). Assistive products and technologies are physical environmental interventions that can either mitigate the impact of impairments by restoring or replacing relevant function (shown in blue), enhance performance and activity by mitigating performance barriers (shown in yellow) or do both in varying degrees (shown in blue and yellow) [13].

The possibilities of AT application are analyzed on the example of Brasil where the importance of developing services and technology in the field of employment of persons with disabilities has been noted [14]. The paper emphasizes the importance of knowledge in the field of creating innovative solutions and services, referring to the process of change in society.

Market factors could increase competitiveness and technological advances, while AT specific factors are constant changes in AT customer needs and desires, intrinsic characteristics of this area, due to new skills acquired through training or rehabilitation, or furthermore loss of skills resulting from degenerative diseases. It is recommended, for future research, to study factors that may hinder AT innovation activities, such as uncertainty demand, identification errors of customer needs, incorrect selection or lack of dissemination of available AT.

Person with intellectual disabilities also can use AT when performing work activities. The authors in this research provided an overview of the effectiveness of various forms of support based on AT in the workplace with a focus on workers' independent ability [15]. The conclusion of the research is to evaluate the impact of ATs on work processes, i.e. to facilitate the work of persons with intellectual disabilities.

Research the employment opportunities of persons with disabilities in South Africa evaluated the effectiveness of the implementation of the Code of Good Practice on the employment of People with Disabilities [16]. The results of the research indicated the need for AT usage to assist in the performance of work tasks of workers with some degree of impairment. A low level of employment of persons with disabilities in the industry sector and in general was also identified.

Based on the user requirements, it is possible to define the functional requirements of the information system in the manufacturing process. Such a fact can be a starting point in designing a form of AT to assist person with disabilities working in manufacturing processes [17]. The key to the development of such information systems is to implement an effective methodology in the selection of appropriate AT.

The work environment is important for the safety of the user where it is located. A study that identified interactions dependent on the type of impairment and the work tasks resulted in recommendations for designing devices based on AT models [18].

To assess the effectiveness of AT in the workplace is descriptive in terms of measuring the efficiency of each device that users use for performing tasks [19].

The impact of AT that can be used in combination with personal assistance services in the workplace is described through case studies [20]. The authors demonstrated how AT can help persons with disabilities to become more independent and productive in the workplace.

The SMARTDISABLE project aimed to develop an appropriate working environment for person with disabilities [21]. The technical work of the project involves the development of a technology scenario for the application of AT based on Ambient Intelligence technology in the workplace. The scenarios consist of an integrated universal smart solution that responds to different types of user impairments. The solution is designed to give person with physical disabilities greater access and efficient use of ICT to execute tasks with minimal effort.

With the development of ICT and computer evolution, work processes are changing. Large enterprises often have the advantage of having well-developed organizational structures to adapt to the capabilities of I4.0 and influence and influence the further technical development of the global work culture. By influencing the work structures and processes of I4.0, it is possible to introduce ATs and thereby increase employment opportunities for person with disabilities [22].

The authors of the study *Use of Assistive Technology in Workplaces of Employees with Physical and Cognitive Disabilities* tried to find the knowledge impact and ICT usage among workers with disabilities on the open labor market. The focus was on the analysis of ICT solutions used in workplaces and how they can influence the improvement of the working skills of person with disabilities [23].

By exploring the possibilities of augmented reality technology, it is possible to develop an intelligent system as a model of AT for workers, based on the projection of intelligent hand tracking [24]. The greatest contribution of the paper, the authors emphasize the presence of a new algorithm for tracking hands. Also, the results of a user study of the system were presented, demonstrating the challenges and possibilities of applying the algorithm to the real system environment.

Using the innovative services it is possible to develop smart solutions for informing person with disabilities who do work processes in smart factories [25]. The smart solution was developed in the form of a smart bracelet and is based on sensor networks and the IoT concept [26]. The aim is to enable real-time informing and effective execution of all their tasks.

5 CONCLUSION

Active participation of persons with disabilities in the work environment is possible through the use of modern ICT. It is demonstrated through the conclusions of the analyzed scientific papers and projects. AT can increase the quality of life of person with disabilities or the elderly with their possibilities and innovative services. The work environment is the basis for the full functioning of person with disabilities in their everyday life. According to the currently available research, there is a very low application of AT in the I4.0 field. The development of Society 5.0 and I5.0 is expected to increase the representation of AT in work processes and thus the greater involvement of persons with disabilities in work processes.

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Contact address:
Marko Periša
University of Zagreb
Faculty of Transport and Traffic Sciences
Department of Information and Communication Traffic
Vukelićeva 4
10000 Zagreb, Croatia
E-mail: marko.perisa@fpz.hr

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til 2019

ACTIVE STRUCTURES IN TRANSPORT – AN INTERACTIVE SIMULATION TOOL

Dragan MARINKOVIĆ[1,2]
Manfred ZEHN[2]

[1)] *University of Niš, Faculty of Mechanical Engineering*
[2)] *TU Berlin, Department of Structural and Computational Mechanics, Germany*

Abstract

Transport calls for reliable, robust and efficient, but less expensive solutions. To respond to this call, engineers keep improving means of transportation in all their aspects. A particularly interesting possibility that attracted numerous researches in the previous two decades is related to active behaviour of transport means. This also includes their load-carrying structures.

Integration of classical, passive structures and multi-functional material based active elements resulted in a novel concept of structural design denoted as active, adaptive, or smart structures.

The distinguishable property of the concept is self-sensing and actuation coupled by control capabilities so that a number of additional functionalities are enabled such as vibration suppression, noise attenuation, structural health monitoring, shape control, etc. Those functionalities offer immense advantages over passive structures, which is reflected in improved robustness, safety and efficiency in their application.

Work in this attractive field of research covers: 1) innovative solutions regarding design of active structures and their elements, 2) development of modelling and simulation tools. When it comes to the latter group of tasks, finite element method, as the most powerful method in the field of structural analysis, is most frequently addressed. Various types of finite elements have been developed for modelling and simulation of coupled-field effects intrinsic for active structures. In this specific work, such elements are combined with a newly developed simulation tool that enables interactive, real-time simulation of active structures. Strain rate proportional damping is implemented to produce active vibration suppression. A few academic cases of shell and truss structures together with a model of a tower crane demonstrate the developed simulation tool and the feasibility of active structure concept.

Figure 1 shows the tower crane model with four active strut elements at the bottom of the tower. The active struts have both sensor and actuator functions at the same time. They measure strains, thus enabling the information about the current strain rate, which is used to determine the actuator force. The crane's jib tip displacement due to an impulse force has been obtained by means of a simulation, whereby the crane is once observed as a passive structure and then again as an adaptive one. Figure 2 shows the obvious differences in the structural behaviour.

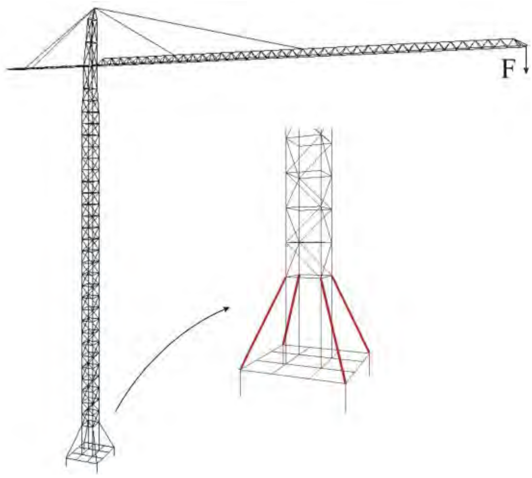

Fig. 1 *Tower crane with active struts*

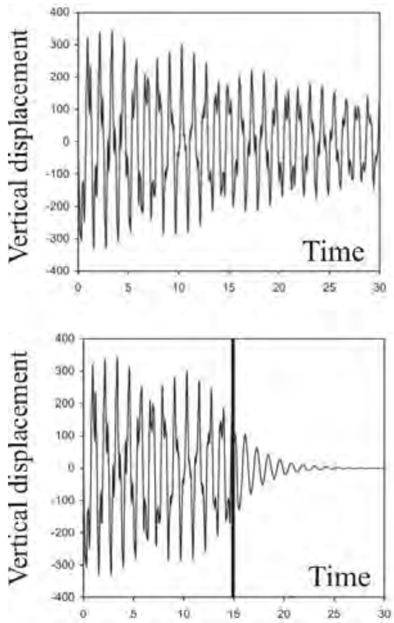

Fig. 2 *Jib tip displacement without and with active struts*

Contact address:
Dragan Marinković
TU Berlin, Germany
University of Niš, Serbia
Faculty of Mechanical engineering

1. SMART LOGISTICS SYSTEMS

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WEIGHTING THE KEY FEATURES AFFECTING SUPPLIER SELECTION USING MACHINE LEARNING TECHNIQUES

Ahmad ABDULLA[1]
George BARYANNIS[1]
Ibrahim BADI[2]

[1] *School of Computing and Engineering, University of Huddersfield*
[2] *Faculty of Engineering, Misurata University, Libya*

Abstract

Supplier selection is an important part of supply chain management (SCM) for any organisation to achieve their objectives. The problem has attracted great interest from academics and practitioners. The selection process starts with determining the most important criteria out of a wide range. Many academic researchers apply multi-criteria decision-making (MCDM) techniques for supplier selection. However, the complexity of such approaches may increase significantly, especially when considering a large number of suppliers and selection criteria. This paper proposes an integrated approach combining machine learning classification with the Analytic Heirarchy Process (AHP) to select and evaluate the most suitable supplier. A Decision Tree (DT) classifier is used to select the most important criteria, instead of applying AHP on the complete set of criteria. The applicability of the approach is demonstrated using data from Libyan companies. Results show that decision trees can successfully lead to a most important subset of selection criteria, which would lead to a less complex application of AHP.

Key words: *Supplier selection, machine learning, decision tree.*

1 INTRODUCTION

Supplier management is one of the key issues of supply chain management, as the cost of raw materials constitutes an important part of the final cost of a product, and most companies have to allocate a considerable amount of their budget on raw materials, up to 70% [1]. Thus, choosing the right suppliers is a critical process, and has a direct effect on the final cost reduction and profitability of a company. Since supplier evaluation and selection is a challenging process for managers of purchasing departments, it has received significant attention in literature. [2], [3].

The criteria for supplier selection are generally highly dependent on individual industries and companies [4], since different companies have different management strategies, enterprise culture and competitiveness. Moreover, company background also impacts supplier selection [5]. Thus, the identification of supplier selection criteria largely requires domain expert assessment and judgment. To select the best supplier, it is necessary to make a trade-off between these qualitative and quantitative factors (weights) some of which may conflict [6].

The supplier selection process includes determining and selecting the important criteria which will be used to select the suitable suppliers from a pool of suppliers. Successful supplier selection reduces purchasing risk, maximises consumer satisfaction, and builds good relationships between purchasers and suppliers [7]. On the other hand, choosing the incorrect supplier may cause an economic problem and impact on the whole company [5]. Especially in today's global economy ineffective supplier selection may have repercussions throughout supply chains worldwide.

Researchers have applied a wide range of multi-criteria decision making (MCDM) techniques to assist purchasing managers in (1) making the right decisions that will help their company to reach its maximum achievement; and (2) evaluating and analysing the decision-making process and the techniques used to achieve the company's objectives. However, MCDM techniques often lead to highly complex models that are difficult to manage and evaluate. On the other hand, the recent proliferation of big data and artificial intelligence (AI) technologies have led many researchers to consider their application in aspects of operations research such as supply chain risk management [8, 9] and supplier selection. Consequently, more and more purchasing managers are increasingly inclined to consider the application of AI techniques in supplier selection processes within their companies, aiming for increased efficiency and performance.

More recently, a subset of AI techniques, machine learning (ML) have received increased attention due its success in various application areas from image classification to game AI to many decision making problems. Particularly in the case of supplier selection, some researchers have proposed the application of ML techniques, alone or in combination with traditional MCDM techniques such as the Analytic Hierarchy Process (AHP) or Data Envelopment Analysis (DEA). In most of these approaches machine learning follows the application of MCDM techniques. However, this would create issues in cases where the number of suppliers or criteria is quite high, increasing the complexity of AHP or DEA higher than what can be easily managed by participants in these processes. Instead, in this paper we propose a reverse integration, where ML is the first step in the supplier selection process, aiming to reduce the complexity of available information (suppliers or criteria) and AHP follows afterwards. Specifically, Decision Tree (DT) models are learned to classify suppliers into two classes: good and bad suppliers. Also, the DT classifer is used to retrieve the criteria importance. These results are then expected to be used in order to simplify the AHP process that follows.

2 LITERATURE REVIEW

Selection of suppliers have received significant attention in supply chain management especially in terms of purchasing departments in any business organisation [10]. A wide range of MCDM methods have been used to select the best suppliers based on criteria identified by purchasing managers [11]. The purchasing managers evaluate the suppliers by evaluation criteria making subjective judgment [12]. Overall, there are two phases in selecting suitable suppliers. First, the decision criteria must be recognised and weighted; then, it should be decided which techniques should be used by decision makers to analyse and determine how each supplier fares against the chosen criteria. Some criteria such as quality, cost and delivery time are quantitative criteria. Conversely, qualitative criteria such as economic stability, the compatibility of top management, and company's history are also important when selecting a supplier. Purchasing managers must implement suitable decision making approaches depending on the situation at hand.

In the remainder of this section, we summarise supplier selection research that combines MCDM techniques (such as AHP and DEA) with machine learning techniques. One of these is NN-DEA [13], which aims to address the issue incomplete data in assessment criteria. AHP-DEA is combined with Neural Network (NN) algorithms: AHP is used for the evaluation of qualitative criteria, while quantitative criteria are evaluated using DEA and the measurement of the efficient suppliers is the responsibility of NN [14]. NN models have also been used in combination with AHP, where AHP is used to calculate criteria weight and NN to select the appropriate suppliers [15, 16]. Similarly, [17] combines AHP with NN but uses Fuzzy Set Theory (FST), while [18] combines FST with AHP and cluster analysis in order to reduce the quantity of alternatives and select the best possible cluster for the selection process.

Another proposed solution for supplier selection is the combination of DEA, DT and NN [19]. DEA is used to divide the suppliers into groups depending on efficiency scores; subsequently, data is used to train DT and NN algorithms, which estimate and evaluate the supplier criteria. It provides accurate classification and regression rate. The drawback of this approach is that it does not make an effort to use the intelligence gathered from groups of experts.

The combination of Genetic Algorithms (GA) with NN algorithms has also been proposed [20]. GA is applied to obtain primary weights and to build a network for improving the search technique for training, whereas NN uses historical data to select the best supplier. The reverse process is followed by [21], where the potential suppliers are subjected by ANN in terms of assessing criteria. After the evaluation process, the determination of top supplier selection is based on GA. The integration of DEA with Support Vector Machines (SVM) is proposed in [22]. DEA is used to calculate efficiency scores and then SVM is used to decide on the best supplier. For the case of green supplier selection, researchers have proposed the ANN-MADA method [23], which integrates DEA, Analytic Network Process (ANP) and NN models. This combination overcomes the constraints associated with DEA models and can address the issue of missing values. A similar combination of DEA and Genetic Programming (GP) is proposed in [24], where GP is used to deal with the complex and time-consuming calculations of the DEA method.

The common characteristic of the approaches summarised in this section is that they propose integrated methods that rely first on the application of MCDM techniques such as AHP and DEA, using their results to learn machine learning models using a number of different algorithms, from NN to DT. While this helps reduce the difficulties of complex calculations in AHP and DEA for large numbers of suppliers, it does not address the fact that the overall AHP and DEA process still remains complex: for instance, even if we use machine learning to facilitate the evaluation process using AHP criteria, we still have to work out the weights of these criteria, which may not be as feasible in cases where there is a large number of criteria or suppliers.

3 PROPOSED METHODOLGY

Based on the research gap identified in the literature review in the previous section, we propose a hybrid model combining ML with AHP, with ML being used to reduce both the number of suppliers and the number of criteria so that AHP can then be applied with lower complexity in terms of time and computation. Note that, while we have chosen AHP as the MCDM method to combine with ML, but this does not preclude using different MCDM methods like DEA. We leave this exploration to future work.

The proposed methodology basically comprises 5 main phases as shown in Figure 1. The first four phases are related to ML while AHP is the final step.

Figure 1 Proposed methodology combining ML and AHP

The remainder of this section explains in detail each phase, as applied in the particular case study of two gas and oil companies in Libya, Srit Oil and Lifeco (Libyan Norwegian Fertilizer Company). The methodology has been implemented in Python using scikit-learn [25].

3.1 Data preparation

The two companies in the case study provided two datasets relevant to the supplier selection process: one dataset containing bidders and decisions on selected bids and one containing supplier evaluation cases. The first dataset of bidders includes approximately 10,000 cases and 30 features, while the other dataset (evaluation dataset) includes 2,300 cases and 23 features. Some features are common between the two datasets.

These datasets were collected from this company's purchasing manager in the form of Excel spreadsheets. For the purpose of data collection, heads and employees in the procurement departments were also interviewed to discuss the process of selecting the best suppliers, as applied based on their experience. This is done on the basis of the best appropriate criteria among the available standards. These interviews helped shed more light into the actual supplier selection process and the criteria involved.

3.1.1 Data cleaning

The success of ML algorithms heavily depends on the quality of data, hence data cleaning are required. In the majority of ML projects, the data cleaning processes actually consume most of the time of the total effort [26]. The basic objective of the process of data cleaning is identification and ratification of errors and copied data for the creation of a reliable dataset. Through such a process, the quality of the training data improves for analytics and the decision making process becomes accurate. For data cleaning purposes, different methods are applied: completion of all missing data, removal of empty rows, correction of errors in the overall structure and data reduction for the purpose of data handling [27].

In this case study, rows missing most values were removed and invalid values and structures (e.g. dates) were corrected. Moreover, columns with duplicate knowledge were removed, such as keeping only supplier codes but not their names.

3.1.2 Feature Selection

Performance of ML algorithms also relies on the initial feature selection phase. In the context of a spreadsheet-based dataset, columns are considered features. For a particular dataset, it is not always expected that the output variables is directly affected by all these columns. Irrelevant features may actually lead to a worse overall model. There are many advantages of using feature selection at the beginning of the process such as reducing the possibility of overfitting, improving classification performance, and reducing time spent during training [28]. In this case study, we applied feature selection using scikit-learn's SelectFromModel meta-transformer.

3.1.3 Data Scaling

Data scaling refers to normalising the available data within a specific range. In some cases, this process contributes to faster calculations in ML algorithms. In this case study, data was normalised between 0 and 1 using MinMaxScaler.

3.1.4 Train-Test Split

As is common in all ML techniques, the initial dataset is divided into two: the training and testing datasets, one used to train the ML algorithm (seen data) and the other used to test the trained algorithm (unseen data). In this case study, the testing dataset encompasses 33% of the data, while the training dataset includes 67% of the data. This separation helps ensure generalisation of ML results.

3.2 Building, training and testing the model

After preprocessing the data, we are ready to apply available ML algorithms on the training and testing datasets. ML algorithms are usually classified as unsupervised, semisupervised, supervised and reinforcement learning. A decisive characteristic, especially in decision-making applications is interpretability. Some approaches, such as neural networks and deep learning use black-box algorithms whose results are not easily interpretable (if at all). In contrast, methods such as decision tree classification are more easily interpretable, since results can be expressed as a sequence of if-then-else rules. As argued in [29], results derived using AI and machine learning can only be successfully integrated in decision-making processes within companies (such as supplier selection) if they are interpretable and justifiable. In our case study, for instance, we cannot expect purchasing and procurement managers to blindly trust the decisions of a black-box machine learning technology, but it would be easier to adopt technologies that supply explanations along with results. For these reasons, we have decided to use a decision tree classifer to build our model. A decision tree is built top-down, starting from the root node and dividing data into various subsets based on particular features features according to the information gain.

A number of different parameters for the decision tree classifier were explored, in order to find the most optimal ones. Trees of maximum depth of 6 seemed to perform better, as higher maximum depths led to overfitting.

3.3 Evaluating the model

To evaluate the results of decision tree models, there are a number of metrics available. These are discussed here.

A confusion matrix is a direct representation of the test results in a prediction model. Columns and rows of the matrix represent prediction class instances and actual class instances, as shown below in Table 1.

Table 1 Confusion matrix

	Class 0 predicted	Class 1 predicted
Class 0 Actual	True Negative	False Negative
Class 1 Actual	False Positive	True Positive

True negatives represent the number of instances that are predicted correctly asnegative. False positives represent the number of times instances are incorrectly predicted as positive. False negatives show the number of instances predicted incorrect as negative. Lastly, trie positives are those instances correctly predicted as positive.

One of the advantages of this matrix is that it determines whether the system is confusing two classes (labels are flipped) or not. This matrix helps quantify how a classifer behaves and its strengths and weaknesses.

The most common evaluation metric is accuracy. Accuracy refers to the fraction of the right predictions ofthe model, defined as follows:

$$\text{Accuracy} = \frac{\textit{number of correct predictions}}{\textit{total number of predications}}$$

In the case of binary classification, negatives and positives can be used to calculate accuracy as follows (where TP is True Positive, TN is True Negative, FP is False Positive, and FN is False Negative):

$$\text{Accuracy} = \frac{TP + TN}{TP + TN + FP + FN}$$

Accuracy can often be misleading, especially in cases of significant data imbalance (where one class contains significantly more samples than the other). Nevertheless, this metric helps in getting a first impression of the performance of the model.

Precision is defined as how frequently the prediction of positive value is correct when it is predicted. It is expressed in terms of true positives and false positives as follows:

$$Precision=\frac{TP}{TP+FP}$$

Recall (or sensitivity) refers to the classifier's ability of finding all positive instances. In other words, it explains the percentage of correctly classified positive cases out of all positive cases. For each class of problems, it is defined as follows:

$$Recall=\frac{TP}{TP+FN}$$

F1 score is defined as the harmonic mean of precision and recall such that the best score is 1.0, and the worst score is 0.0. Speaking generally, F1 scores are low as compared to the accuracy measures as precision is embedded in their computation, followed by recall. F1 is defined as follows:

$$F1=2*\frac{Precision*Recall}{Precision+Recall}$$

Support is referred to as the number of times the class occurred in the dataset that is specified. Structural weakness may be indicated if there is any imbalanced support in the data that is provided in training in the classifier's reported scores and could stipulate the requirement for stratified rebalancing and sampling. Support between models doesn't change; instead, the evaluation process is diagnosed.
A classification report combines the results of precision, recall, F1 and support, allowing comparison among the different metrics. It provides a better understanding of the behaviour of a classifier compared to accuracy, which can hide the weaknesses of the results of one class.

3.4 Integrating with AHP

The classification model built in the previous steps is used in two ways to simplify the AHP process. First, feature importances are calculated in order to decide which criteria of the supplier selection process are the most important. Also, the classifier is used to decide which suppliers are considered good and which are considered bad. Then, AHP operates on a reduced set of criteria and suppliers: only the most important features are used as criteria and only suppliers classified as good are considered in order to find the best out of all. This helps considerably reduce the complexity of AHP, allowing for a quicker decision-making process that is, however, still interpretable, due to the use of decision tree classification in the previous steps.

4 RESULTS

This section consists of the discussion of the results of classification of suppliers using the metrics discussed earlier in Section 3.3.

4.1 Evaluation results

Classification accuracy of the decision tree classifier was 0.7615 on the training dataset and 0.765 on the testing dataset. Table 2 shows the confusion matrix of the decision tree classifier.

Table 2 Confusion Matrix of DT

	Bad supplier	Good supplier
Bad supplier	1420	121
Good supplier	411	299

The classification report is shown in Table 3 and Figure 2.

Table 3 DT classification report

	f1-score	precision	recall	support
Bad supplier	0.8422301	0.7755325	0.92148	1541
Good supplier	0.5292035	0.71190476	0.421127	710
micro avg	0.7636606	0.7636606	0.763661	2251
macro avg	0.6857168	0.74371863	0.671303	2251
weighted avg	0.7434967	0.75546333	0.763661	2251

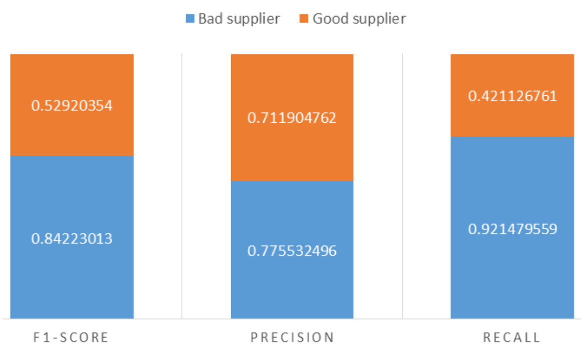

Figure 2 DT classification report

We note that decision tree scores for classification report (recall, precision, f1-score) was different for each class, class 0 (bad supplier) was higher accuracy than class 1 (good supplier).

4.2 Feature importance results

The results of feature importance are shown in Figure 4. It is clear that the highest importance is for the feature of technical acceptance. This feature explains whether the technical quality of the product is good enough to be accepted. Best price is noted as the second most important feature. Both of these results are expected, since purchasing and procurement managers are expected to prioritise quality, price and the trade-off between. These results lend support to this commonly observed behaviour in supplier selection processes.
The results of our case study currently concern only the machine learning phases of the proposed methodology. In the next steps selected experts are expected to be using the results of the decision tree classifier to make pairwise comparisons of the most important criteria in order to select the best out of those suppliers that have been classified as good.

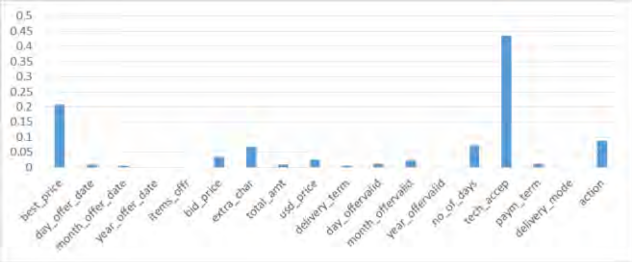

Figure 3 Feature importances

5 CONCLUSION

This paper proposed a hybrid methodology for supplier selection to address the high complexity of solutions that rely only on traditional MCDM approaches, such as AHP and DEA. The proposed methodology employs a decision tree classifier to classify suppliers into good and bad and to determine which features are the most important in the supplier selection process, based on historical data. These results are then used to keep only the good suppliers and only the most important criteria, which are then fed to an AHP instance, which is significantly less complex. The applicability of the proposed methodology is shown through the case study of two oil and gas companies in Libya. As future research, we intend to complete the case study by applying AHP based on the results of the decision tree classifiers using experts from the two companies. We also plan to explore alternative hybrid methodologies, for instance replacing AHP with DEA or considering classifiers other than decision trees. Finally, it would be interesting to explore whether our hybrid methodology can be delivered in the form of a service-based application [30-32], to be consumed by any purchasing or procurement department willing to utilise automated supplier selection functionality.

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Contact addresses:
Ahmad Abdulla
School of Computing and Engineering
University of Huddersfield
Queensgate
Huddersfield HD1 3DH
United Kingdom
E-mail: Ahmad.Abdulla@hud.ac.uk, g.bargiannis@hud.ac.uk

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AN INTEGRATED FUCOM – ROUGH SAW MODEL FOR SUSTAINABLE SUPPLIER EVALUATION

Elmina DURMIĆ[1]
Milovan TOMAŠEVIĆ[2]
Marko VASILJEVIĆ[1]
Željko STEVIĆ[1]
Prasenjit CHATTERJEE[3]

[1)]University of East Sarajevo, Faculty of Transport and Traffic Engineering Doboj, Bosnia and Herzegovina
[2)]Faculty of Information Studies in Novo Mesto, Slovenia
[3)]Department of Mechanical Engineering, MCKV Institute of Engineering, India

Abstract

In recent decades, due to the rapid consumption of natural resources and the need for environmental protection, sustainability in supply chain management has emerged as an increasingly important issue. Therefore, in this paper, supplier selection has been performed in order to achieve sustainability, taking into account economic, social and environmental elements. For this purpose, an integrated FUCOM - Rough SAW model has been applied. The assessment of 21 criteria grouped at two levels has been carried out by an expert team according to the needs of the company whose main activity is lime production. To obtain the criterion weight values, the FUCOM (FUll COnsistency Method) has been applied, which allows solving the problem of decision-makers' subjective judgment. In order to avoid uncertainty and imprecision in the supplier evaluation process, integration with the Rough SAW method, which is used for ranking and supplier selection, has been applied. In order to check the stability of the proposed model, a sensitivity analysis has been performed throughout two phases. The first phase involves changing the weights of the criteria throughout a total of 12 scenarios, while the second phase involves a comparative analysis using other MCDM methods.

Key words: *FUCOM, Rough SAW, sustainability, supplier*

1. INTRODUCTION

In response to the changes caused by globalization, businesses are increasingly paying attention to logistics. With the development of logistics, supply chains are developed and their importance strengthened. Christopher [4] defines the supply chain as upstream and downstream relationships with suppliers and customers in order to deliver superior customer value at less cost to the supply chain as a whole [4].

A well-designed system of supply chain management is important for improving a competitive advantage in an era of international economy and accelerated development of information technologies [7]. Procurement of materials as a separate logistics subsystem plays an important role in achieving the efficiency of a sustainable supply chain. In a procurement process, it is necessary to take into account the adequate selection of suppliers, which will greatly increase competitiveness in the market. Sustainable supplier selection is an continuous process that requires consideration of a number of criteria needed to reach the decisions on the selection of the most appropriate supplier [3,8,1]. Supplier evaluation also takes into account tangible and intangible factors, which are not always very clearly defined [2]. Suppliers have to meet a number of requirements and be prepared to adapt their business policies to their customers at all times. In order to do this, it is necessary to take into account all three aspects of sustainability: environmental, economic and social. In fact, it is claimed that the long-term profitability and existence of a company is best if it is based on a balance between economic, environmental and social goals [5]. Accordingly, in this paper, the evaluation of suppliers has been performed,taking into account 21 criteria from the aspect of all sustainability factors.

This study examined the problem of sustainable evaluation of supplier performance and selection in supply chains by presenting an integrated FUCOM – Rough SAW model. The assessment and selection of suppliers has been performed on the basis of an equal number of criteria by all aspects of sustainability.

This paper has several goals. The first refers to the consideration of the theory of multi-criteria problems that are largely dominated by uncertainties and dilemmas. This goal is achieved by applying the Rough SAW method. The second goal is to reduce subjectivity in group decision-making and to allow more precise identification of the preferences of decision-makers. This is achieved by integrating the FUCOM method and the Rough SAW algorithm. The third goal is to optimize the procurement process, i.e. to evaluate and select a sustainable supplier in a lime company. These goals reflect the contribution of this research.

After the introductory part, the paper is written throughout four other sections. The second section presents the proposed model in this study. The FUCOM algorithm is briefly presented, as well as the operations with rough numbers. The Rough SAW method is given at the end of this section. The third section consists of the results with the calculation presented in detail using the proposed integrated model. A sensitivity analysis, which includes changing the weight of the criteria throughout a total of 12 scenarios and applying other methods to compare the proposed model, is performed in the fourth section. Finally, the fifth section is the conclusion and discussion of the results obtained.

2. METHODS

2.1. FUCOM method

The FUCOM method was developed by Pamučar et al. [9] for determining the weights of criteria. It represents a new method that according to the authors is a better method than AHP (Analytic Hierarchy Process) and BWM (Best Worst Method). The following section presents a procedure for obtaining the weighting coefficients of criteria using FUCOM:

Step1.The first step is to rank the criteria from a predefined set of evaluation criteria $C = \{C_1, C_2, \dots, C_n\}$. Ranking is performed according to the significance of the criteria, i.e. from the criterion that we expect to have the highest weighting coefficient towards the criterion of the least significance. Thus, we obtain ranked criteria according to the expected values of the weighting coefficients

$$C_{j(1)} > C_{j(2)} > \dots > C_{j(k)} \tag{1}$$

where k represents the rank of the observed criterion. If there are estimates that two or more criteria have the same significance, a sign of equality is placed between the criteria instead of ">" in Expression (1).
Step 2. In the second step, a mutual comparison of ranked criteria is made and comparative significance$(\varphi_{k/(k+1)})$, $= 1,2,\dots,n$, is determined,where k represents the ranking of the evaluation criteria. The comparative significance of the evaluation criteria $(\varphi_{k/(k+1)})$ presents the advantage that the criterion of rank has over the criterion of rank$C_{j(k+1)}$. Thus, we obtain vectors of the comparative significance of the evaluation criteria

$$\Phi = (\varphi_{1/2}, \varphi_{2/3}, \dots, \varphi_{k/(k+1)}) \tag{2}$$

Step 3. In the third step, the final values of the weighting coefficients of the evaluation criteria $(w_1, w_2, \dots, w_n)^T$are calculated. The final values of the weighting coefficients should satisfy two conditions: (1) The ratio of the weighting coefficients is equal to the comparative significance among the observed criteria $(\varphi_{k/(k+1)})$, which is defined in Step 2, i.e. that the following condition is fulfilled

$$\frac{w_k}{w_{k+1}} = \varphi_{k/(k+1)} \tag{3}$$

(2)In addition to condition (3), the final values of the weighting coefficients should satisfy the condition of mathematical transitivity, i.e.that$\varphi_{k/(k+1)} \otimes \varphi_{(k+1)/(k+2)} = \varphi_{k/(k+2)}$. Since$\varphi_{k/(k+1)} = \frac{w_k}{w_{k+1}}and\varphi_{(k+1)/(k+2)} = \frac{w_{k+1}}{w_{k+2}}$, we obtain that$\frac{w_k}{w_{k+1}} \otimes \frac{w_{k+1}}{w_{k+2}} = \frac{w_k}{w_{k+2}}$. Thus, we gain a second condition that should be satisfied by the final values of the weighting coefficients of the evaluation criteria

$$\frac{w_k}{w_{k+2}} = \varphi_{\frac{k}{k+1}} \otimes \varphi_{\frac{k+1}{k+2}} \tag{4}$$

Based on the defined settings,we can define a final model for determining the final values of the weighting coefficients of the evaluation criteria

$$\begin{aligned}
&\min \chi \\
&s.t. \\
&\left|\frac{w_{j(k)}}{w_{j(k+1)}} - \varphi_{k/(k+1)}\right| = \chi,\ \forall j \\
&\left|\frac{w_{j(k)}}{w_{j(k+2)}} - \varphi_{k/(k+1)} \otimes \varphi_{(k+1)/(k+2)}\right| = \chi,\ \forall j \\
&\sum_{j=1}^{n} w_j = 1,\ \forall j \\
&w_j \geq 0,\ \forall j
\end{aligned} \tag{5}$$

2.2. Rough set theory

In rough set theory, any vague idea can be presented as a pair of exact concepts based on the lower and upper approximation as shown in Figure 1.

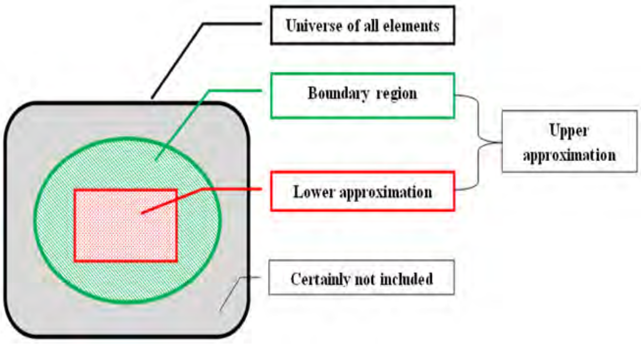

Fig. 1*Basic concept of rough set theory*

Assume that$U$ is a universe consisting of all objects, $Y$is an arbitraryobject of$U$, $R$is a set of$t$classes (G_1;G_2; ... ;G_t) that include all objects in U, R (G_1;G_2; ... ;G_t). If these classes are determinedasG_1<G_2<...<G_t, then$\forall Y \in U, G_q \in R, 1 \leq q \leq t$lowerapproximation$\left(\underline{Apr}(G_q)\right)$, upper approximation $\left(\overline{Apr}(G_q)\right)$andthe boundary region$\left(Bnd(G_q)\right)$of class$G_q$according to[14]is defined as:

$$\underline{Apr}(G_q) = \cup\left\{Y \in \frac{U}{R(Y)} \leq G_q\right\} \tag{6}$$

$$\overline{Apr}(G_q) = \cup\left\{Y \in \frac{U}{R(Y)} \geq G_q\right\} \tag{7}$$

$$Bnd(G_q) = \cup\left\{Y \in \frac{U}{R(Y)} \neq G_q\right\} = \left\{Y \in \frac{U}{R(Y)} \geq G_q\right\} = \cup \left\{Y \in \frac{U}{R(Y)} \leq G_q\right\} \tag{8}$$

Then,$G_q$can be presented as a rough number $(RN(G_q)$, which is determined by certain lower limit$(\underline{Lim}(G_q))$and upper limit$(\overline{Lim}(G_q))$, where:

$$\underline{Lim}(G_q) = \frac{1}{M_L}\sum R(Y)|Y \in \underline{Apr}(G_q) \tag{9}$$

$$\overline{Lim}(G_q) = \frac{1}{M_U}\sum R(Y)|Y \in (\overline{Apr}(G_q) \tag{10}$$

$$RN(G_q) = [\underline{Lim}(G_q), \overline{Lim}(G_q)] \tag{11}$$

whereM_L,M_U are numbers contained in$\underline{Apr}(G_q)$ and$\overline{Apr}(G_q)$, respectively.

The differences between them are expressed as a rough boundary interval

$$IRBnd(G_q) = \overline{Lim}(G_q) - \underline{Lim}(G_q) \quad (12)$$

Operations for two rough numbers $RN(\alpha) = [\underline{Lim}(\alpha), \overline{Lim}(\alpha)]$ and $RN(\beta) = [\underline{Lim}(\beta), \overline{Lim}(\beta)]$ according to (Zhai et. al., 2009) are:

Adding (+) two rough numbers (α) and (β)

$$RN(\alpha) + RN(\beta) = [\underline{Lim}(\alpha) + \underline{Lim}(\beta), \overline{Lim}(\alpha) + \overline{Lim}(\beta)] \quad (13)$$

Subtracting (-) two rough numbers (α) and (β)

$$RN(\alpha) - RN(\beta) = [\underline{Lim}(\alpha) - \overline{Lim}(\beta), \overline{Lim}(\alpha) - \underline{Lim}(\beta)] \quad (14)$$

Multiplying (×) two rough numbers (α) and (β)

$$RN(\alpha) \times RN(\beta) = [\underline{Lim}(\alpha) \times \underline{Lim}(\beta), \overline{Lim}(\alpha) \times \overline{Lim}(\beta)] \quad (15)$$

Dividing (÷) two rough numbers (a) and (b)

$$RN(\alpha) \div RN(\beta) = [\underline{Lim}(\alpha) \div \overline{Lim}(\beta), \overline{Lim}(\alpha) \div \underline{Lim}(\beta)] \quad (16)$$

The scalar multiplication of two rough numbers (α), where μ is a non-zero value.

$$\mu \times RN(\alpha) = [\underline{\mu \times Lim(\alpha)}, \mu \times \overline{Lim}(\alpha)] \quad (17)$$

2.3. Rough SAW method

The SAW method represents a simple and easily applicable multi-criteria decision-making method. However, using only crisp numbers, it is impossible to obtain results that treat uncertainties and objectivity appropriately. Therefore, a new approach combining the SAW method and rough numbers is presented below. The Rough SAW method consists of the following steps [12]:

Step 1: Defining a problem that needs to be solved and that consists of *m* alternatives and *n* criteria.

Step 2: Forming a group of experts who evaluate alternatives by all criteria using the linguistic scale shown in [12]. Based on the linguistic scale, the expert group evaluates the alternatives taking into account a type of criteria (benefit or cost). It is very important for this kind of solving engineering problems that the evaluation of potential solutions be carried out adequately, which involves the application of the above or some other similar scales.

Step 3:Converting individual matrices into a group rough matrix. Each individual expert matrix *k1, k2*, ..., *kn*have to be converted into a rough group matrix by applying Equations (6) - (18):

$$RGM = \begin{bmatrix} [x_{11}^L, x_{11}^U] & [x_{12}^L, x_{12}^U] & \cdots & [x_{1m}^L, x_{1m}^U] \\ [x_{21}^L, x_{21}^U] & [x_{22}^L, x_{22}^U] & \cdots & [x_{2m}^L, x_{2m}^U] \\ \vdots & \vdots & \ddots & \vdots \\ [x_{m1}^L, x_{m1}^U] & [x_{m2}^L, x_{m2}^U] & \cdots & [x_{mm}^L, x_{mm}^U] \end{bmatrix} \quad (18)$$

Step 4: Group matrix normalization applying Equations (19) and (20):

$$r_{ij} = \frac{[x_{ij}^L; x_{ij}^U]}{max[x_{ij}^{+L}; x_{ij}^{+U}]} for C_1, C_2, \ldots, C_n \epsilon B \quad (19)$$

$$r_{ij} = \frac{min[x_{ij}^{-L}; x_{ij}^{-U}]}{[x_{ij}^L; x_{ij}^U]} for C_1, C_2, \ldots, C_n \epsilon C \quad (20)$$

The values are marked with$^+$ and$^-$in orderto facilitate the identification of the values that belong to different types of criteria. The previously written equations can be expressed in a simpler way as:

$$r_{ij} = \left[\frac{x_{ij}^L}{x_{ij}^{+U}}; \frac{x_{ij}^U}{x_{ij}^{+L}}\right] for C_1, C_2, \ldots, C_n \epsilon B \quad (21)$$

$$r_{ij} = \left[\frac{x_{ij}^{-L}}{x_{ij}^U}; \frac{x_{ij}^{-U}}{x_{ij}^L}\right] for C_1, C_2, \ldots, C_n \epsilon C \quad (22)$$

and a normalized matrix is obtained, as follows:

$$Rn = \begin{bmatrix} [r_{11}^L, r_{11}^U] & [r_{12}^L, r_{12}^U] & \cdots & [r_{1m}^L, r_{1m}^U] \\ [r_{21}^L, r_{21}^U] & [r_{22}^L, r_{22}^U] & \cdots & [r_{2m}^L, r_{2m}^U] \\ \vdots & \vdots & \ddots & \vdots \\ [r_{m1}^L, r_{m1}^U] & [r_{m2}^L, r_{m2}^U] & \cdots & [r_{mm}^L, r_{mm}^U] \end{bmatrix} \quad (23)$$

Step 5: Weighting the normalized matrix:

$$\begin{gathered} Vn = [v_{ij}^L; v_{ij}^U]_{mxn} \\ v_{ij}^L = w_j^L \times r_{ij}^L, i = 1,2, \ldots m, j \\ v_{ij}^U = w_j^U \times r_{ij}^U, i = 1,2, \ldots m, j \end{gathered} \quad (24)$$

where w_j^L is the lower limit, and w_j^U is the upper limit of criterion weight expressed as a rough number obtained by applying a rough AHP or a rough BWM as is the case in this paper.

Step 6: Summing up all the values of the alternatives obtained (summing by rows):

$$S = [s_{ij}^L; s_{ij}^U] \quad (25)$$

Step 7: Ranking alternatives by decreasing values, i.e. the highest value represents the best solution. To facilitate ranking of potential solutions, a rough number can be converted to crisp.

3. RESULTS

The selection of a sustainable supplier depends on the precise determination and selection of appropriate criteria and their evaluation. The criteria and alternatives were evaluated by a group of employed experts with regards to the needs of Carmeuse (Bosnia and Herzegovina), a company for lime production. This group consists of three decision-makers. The criteria for selecting a sustainable supplier are as follows:

- Sub-criteria of the economic criteria group C_1: C_{11} - cost/price, C_{12} - quality, C_{13} - flexibility, C_{14} -

productivity, C_{15} - financial capacity, C_{16} - partnerships and C_{17} - eco-innovation.

- Sub-criteria of the social criteria group C_2: C_{21} - reputation, C_{22} - safety at work, C_{23} - workers' rights, C_{24} - local community influence, C_{25} - employee training, C_{26} - respect for rights and policies and C_{27} - release of information.
- Sub-criteria of the environmental criteria group C_3: C_{31} - ecological image, C_{32} - recycling, C_{33} - pollution control, C_{34} - environmental management system, C_{35} - ecological products, C_{36} - resource consumption and C_{37} - green competencies.

A complete calculation of the criteria is presented in [6], obtaining the following values of the criteria, which are further used in the calculation with the Rough SAW method:

$$w_{11} = 0.084, w_{12} = 0.135, w_{13} = 0.058, w_{14} = 0.083,$$
$$w_{15} = 0.055, w_{16} = 0.060, w_{17} = 0.045,$$
$$w_{21} = 0.044, w_{22} = 0.060, w_{23} = 0.031, w_{24} = 0.024,$$
$$w_{25} = 0.033, w_{26} = 0.040, w_{27} = 0.037,$$
$$w_{31} = 0.029, w_{32} = 0.037, w_{33} = 0.046, w_{34} = 0.027,$$
$$w_{35} = 0.030, w_{36} = 0.019, w_{37} = 0.023$$

The evaluation of the alternatives by three decision-makers is shown in Table 1. Since the selection of suppliers is influenced by three decision-makers, it is necessary to convert the individual matrices of each decision-maker into a group rough matrix by applying Equations (6) - (11).

Table 1*Evaluation of the alternatives by three decision-makers*

	A_1			A_2			A_3			A_4		
	DM_1	DM_2	DM_3	DM_1	DM_2	DM_3	DM_1	DM_2	DM_3	DM_1	DM_2	DM_3
C_{11}	1	2	1	1	3	3	1	2	2	1	3	2
C_{12}	7	7	7	7	6	6	7	7	6	7	6	6
C_{13}	5	4	5	5	4	4	7	6	5	7	6	6
C_{14}	7	6	6	6	5	6	7	6	5	7	6	6
C_{15}	5	4	5	6	5	5	6	6	6	7	7	6
C_{16}	7	7	7	6	5	5	6	6	6	6	6	7
C_{17}	6	5	5	6	5	4	6	5	5	7	6	5
C_{21}	5	5	4	6	6	5	7	7	6	7	7	6
C_{22}	5	4	5	6	5	4	7	6	4	7	6	5
C_{23}	5	5	5	3	6	5	6	6	4	6	5	4
C_{24}	3	3	2	3	3	3	4	4	3	4	4	4
C_{25}	3	3	3	6	5	4	6	4	3	6	5	5
C_{26}	5	4	4	6	5	5	6	6	5	6	6	6
C_{27}	3	3	2	5	4	3	6	6	4	6	6	4
C_{31}	4	4	5	4	4	5	5	5	4	6	6	5
C_{32}	6	6	5	5	5	5	6	6	5	6	6	4
C_{33}	4	4	6	5	5	5	6	5	4	5	6	4
C_{34}	3	3	4	4	4	4	6	5	2	6	5	3
C_{35}	5	4	4	4	3	4	6	5	3	5	4	5
C_{36}	4	5	5	4	5	5	4	5	6	3	4	3
C_{37}	3	4	3	4	3	4	5	4	3	5	5	4

Converting individual matrices into a group rough matrix is performed as follows:

$\tilde{x}_{11} = \{1,2,1\}; \underline{Lim}(1) = 1, \overline{Lim}(1) = \frac{1}{3}(1 + 2 + 1) = 1.33; \underline{Lim}(2) = \frac{1}{3}(1 + 2 + 1) = 1.33, \overline{Lim}(2) = 2;$

$$RN(x_{11}^1) = [1; 1.33]; RN(x_{11}^2) = [1.33; 2];$$

$$x_{11}^L = \frac{x_{11}^1 + x_{11}^2 + x_{11}^1}{S} = \frac{1 + 1.33 + 1}{3} = 1.11$$

$$x_{11}^U = \frac{x_{11}^1 + x_{11}^2 + x_{11}^1}{S} = \frac{1.33 + 2 + 1.33}{3} = 1.55$$

After obtaining the group rough matrix,its normalization has to be performed using Equations (18) - (21) in order to obtain the normalized matrix shown in Table 2, while the weighted normalized matrix obtained in the followingstep, is achieved by applying Equation (23).The normalization of group matrix elements for benefit criteria is performed as follows:

$$\tilde{r}_{12} = \left[\frac{x_{ij}^L}{x_{ij}^{+U}}; \frac{x_{ij}^U}{x_{ij}^{+L}}\right] = \left[\frac{7.00}{7.00}; \frac{7.00}{7.00}\right] \rightarrow \tilde{r}_{12} = [1.000;\ 1.00]$$

and for cost criteria as follows:

$$\tilde{r}_{11} = \left[\frac{x_{ij}^{-L}}{x_{ij}^U}; \frac{x_{ij}^{-U}}{x_{ij}^L}\right] = \left[\frac{1.11}{1.55}; \frac{1.55}{1.11}\right] \rightarrow \tilde{r}_{11} = [0.176; 1.396]$$

The normalization matrix is weighted as follows: $v_{13}^L = [w_{13}^L \times r_{13}^L] = [0.679 \times 0.058] \rightarrow v_{13}^L = [0.039]$
$v_{13}^U = [w_{13}^U \times r_{13}^U] = [0.800 \times 0.058] \rightarrow v_{13}^U = [0.046]$
V_{13} =[0.039,0.046]

Table 2*The normalized matrix*

	A1	A2	A3	A4
C_{11}	[0.716, 1.396]	[0.399, 0.82]	[0.587, 1.069]	[0.444, 1.033]
C_{12}	[1, 1]	[0.873, 0.936]	[0.921, 0.984]	[0.873, 0.936]
C_{13}	[0.679, 0.8]	[0.627, 0.745]	[0.84, 1.064]	[0.933, 1.072]
C_{14}	[0.933, 1.072]	[0.832, 0.964]	[0.84, 1.064]	[0.933, 1.072]
C_{15}	[0.646, 0.758]	[0.742, 0.86]	[0.871, 0.930]	[0.936, 1.068]
C_{16}	[1, 1]	[0.73, 0.793]	[0.857, 0.857]	[0.873, 0.936]
C_{17}	[0.789, 1.009]	[0.692, 1]	[0.786, 1.009]	[0.846, 1.182]
C_{21}	[0.646, 0.7]	[0.791, 0.913]	[0.936, 1.068]	[0.936, 1.068]
C_{22}	[0.685, 0.889]	[0.692, 1]	[0.752, 1.162]	[0.846, 1.182]
C_{23}	[0.849, 0.917]	[0.925, 1.081]	[0.830, 1.061]	[0.764, 1.009]
C_{24}	[0.613, 0,745]	[0.75, 0.75]	[0.863, 0.973]	[1, 1]
C_{25}	[0.541, 0.587]	[0.811, 1.076]	[0.76, 1]	[0.921, 1.086]
C_{26}	[0.685, 0.758]	[0.852, 0.982]	[0.908, 0.982]	[1, 1]
C_{27}	[0.424, 0.591]	[0.606, 0.92]	[0. 846, 1.182]	[0.846, 1.182]
C_{31}	[0.698, 0.835]	[0.698, 0.835]	[0.756, 0.897]	[0.925, 1.081]
C_{32}	[0.925, 1.081]	[0.849, 0.917]	[0.925, 1.081]	[0.83, 1.061]
C_{33}	[0.767, 1.022]	[0.909, 1]	[0.818, 1.1]	[0.818, 1.1]
C_{34}	[0.577, 0.888]	[0.742, 1]	[0.609, 1.32]	[0.722, 1.348]
C_{35}	[0.763, 1.022]	[0.640, 0.874]	[0.722, 1.211]	[0.826, 1.099]
C_{36}	[0.636, 0.798]	[0.636, 0.798]	[0.565, 0.789]	[0.876, 1.141]
C_{37}	[0.636, 0.798]	[0.706, 0.874]	[0.716, 1.011]	[0.91, 1.099]

After weighting the normalized matrix, the values for all alternatives are summarized by rows and the final ranking of the alternatives is obtained, which is shown in Table 6. The ranking is made in decreasing order, where the highest value represents the best solution and the lowest worst. The table also shows the conversion of a rough number into crisp by applying the average value of the lower and upper limits of the rough number.

Table 6*Results and ranking of alternatives*

	s_{ij}^L	s_{ij}^U	AV	Rank
A_1	0.769	0.939	**0.854**	**3**
A_2	0.740	0.909	**0.825**	**4**
A_3	0.811	1.036	**0.924**	**2**
A_4	0.847	1.063	**0.955**	**1**

Alternative 4 is the most acceptable solution according to the results obtained.

4. SENSITIVITY ANALYSIS

4.1. Changing the weights of criteria

The aim of sensitivity analysis by changing the weights of the criteria is to determine the sensitivity of the model to changes in the weights. For this purpose, 12 scenarios have been formed in which the weights of the criteria have been modeled. The rankings of the alternatives in the formed scenarios are shown in Figure 2. The first$(C_{11}, C_{12}, C_{13}, C_{14}, C_{15}, C_{16}, C_{22})$scenario impliesreduction of the seven most important criteria by 4% and increase of the others by 2%, while, in the second scenario, the economic criteria have increased by 3%, while the others have decreased by 1.5%. In the third set, the criteria belonging to the economic group have reduced by 4%, while the criteria of the social group haveincreasedproportionally, and the value of environmental criteria remains unchanged.The fourth scenario presents a reverse situation from the third, where economic criteria have reduced by 3%, environmental criteria have increased proportionally, and the social criteria remain unchanged. The fifth scenario involves the reduction of the economic criteria by 4% and increase of the social and environmental criteria by 2%, while, in the sixth set, the seven least significant criteria $(C_{23}, C_{24}, C_{31}, C_{34}, C_{35}, C_{36}, C_{37})$have increased by 4% and the othershave decreased by 2%. Inthe seventh scenario, the value of social criteriahas decreased by 2% and the values of environmental criteriahaveincreased proportionally, while economic criteria remain the same.In the eighth scenario, decision-making is based only on economic criteria, in the ninth, it is based on social criteria and, in the tenth,it is based onenvironmental criteria. The eleventh scenario represents the elimination of the seven most significant criteria, while the seven least significant criteria are eliminated in the twelfth scenario.

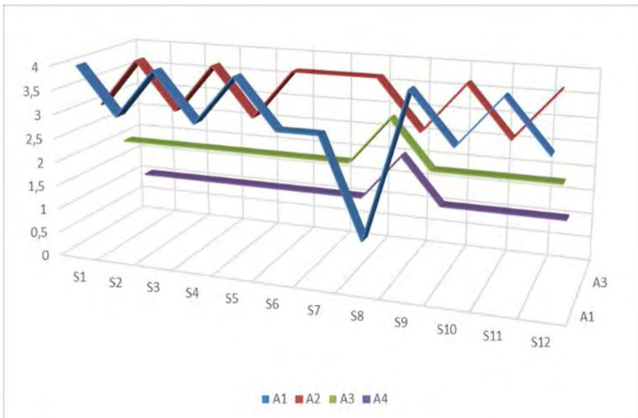

Fig 2 *A sensitivity analysis by changing the weights of criteria*

The results show that the model is sensitive to changes in the weights of the criteria. The rankings of alternatives change in the first, third, fifth, eighth, ninth and eleventh scenarios, which means that the most significant criteria play a very important role in a decision-making process. This is confirmed by the fact that there are rank changes in the first scenario, when the seven most significant criteria are reduced, and in the eleventh scenario, when the seven most significant criteria are eliminated. The initial scenario of this study has a complete correlation with six scenarios (2, 4, 6, 7, 10, 12), which means that the rankings of the alternatives remain the same completely. The reason for this result is that there is no major change in the values of the most important economic criteria. The initial scenario has the lowest correlation with the eighth scenario in which the selection of suppliers is made only on the basis of economic criteria, whereby the ranking of three alternatives changes. The only alternative that does not change its rank is Alternative 2, which ranks last in the ranking as the worst solution. In other scenarios, as noted above, the rankings of two alternatives A_1 and A_2 change, where they replace their positions.

Changes in the rankings in the third and fifth scenarios are due to the fact that the values of economic criteria have decreased, which, as already stated, have the greatest influence on the first level of decision-making, and the values of less significant environmental and social criteria have increased. The change also occurs in the first and eleventh scenarios, where the reason for changing the rank is the reduction and elimination of the seven most significant criteria. In the ninth section, the change of rank occurs because the selection of suppliers is made only on the basis of the social criteria, which have the least impact. It is important to emphasize that the two alternatives A_4 and A_3, which represent the best solution, do not change the rankings in either scenario, which means that they are insensitive to changes in the significance of the criteria.

4.2. A comparative analysis

The stability of the obtained results of the applied methodology has been examined by a comparative analysis throughout the application of other methods. The proposed model has been compared with other approaches developed more recently: Rough ARAS [10], Rough WASPAS [13] and Rough MABAC [11]. The obtained results show that the developed integrated FUCOM-RSAW model is in complete correlation with the applied R-ARAS, R-WASPAS and R-MABAC models, which means that the applied model is stable. The ranks of the alternatives remain the same in all models, i.e. Alternative 4 is the best solution, followed by Alternative 3, then Alternative 1 and ultimately the worst solution is Alternative 2.

5. CONCLUSION

As a logistics subsystem, procurement plays an essential role in achieving a sustainable supply chain, and suppliers play a key role in a procurement process. Efficiency in day-to-day business requires decision-making that will save costs but also meet customer needs, so every business should strive to provide good andhigh quality suppliers in order for their business to achieve its goals and operate profitably in the environment and thereby satisfy the wishes and needs of existing and potential customers. Since manufacturing processes are complex and numerous, so are the requirements of manufacturers towards suppliers. The number of criteria (requirements) is constantly increasing, leading decision-makers to a situation where they can no longer compare the growing number of suppliers with the increasing number of criteria. Therefore, in this study, a multi-criteria decision-making methodology has been applied to overcome this problem.

An integrated FUCOM - Rough SAW model was used for supplier evaluation. The evaluation was performed on the basis of 21 criteria classified into a two-level hierarchical structure. The FUCOM method was applied to determine the significance of the criteria. First, the values of the main criteria, economic, social and environmental, were determined. Then, the weights of all sub-criteria were calculated for each major group of the criteria. The Rough SAW method was applied to rank and select suppliers from a potential set. The results obtained show that the fourth supplier is the best solution. The validity of the final results was determined through a sensitivity analysis. In the sensitivity analysis, 12 scenarios that imply a change in the weight of the criteria were formed first. After that, the results were compared using R-ARAS, R-WASPAS and R-MABAC methods, which also confirmed the previous results, which means that the applied FUCOM-RSAW model allows obtaining stable solutions to the problem of selecting a sustainable supplier.

Future research related to this paper refers to the integration of other MCDM methods with rough numbers when it comes to the applied methodology. In addition, it is possible to define an extension of the set of supplier evaluation criteria from a practical aspect.

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Contact address:
Elmina Durmić
University of East Sarajevo, Faculty of Transport and Traffic Engineering
Doboj, Bosnia and Herzegovina

UNIVERSITY OF NIS FACULTY OF MECHANICAL ENGINEERING

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NORMALIZED WEIGHTED GEOMETRIC DOMBI BONFERONI MEAN OPERATOR WITH INTERVAL GREY NUMBERS: APPLICATION IN MULTICRITERIA DECISION MAKING

Dragan PAMUČAR [1]

[1)] *Department of logistics, Military academy, University of defence in Belgrade, Serbia*

Abstract

The main purpose of this paper is to provide a multi-criteria decision-making that combines interval grey numbers and normalized weighted geometric Dombi-Bonferroni mean operator to address the situations where attribute values take the form of interval grey numbers under uncertain information. As in recent decade, evaluation objects are becoming more and more complicated, the interval grey numbers (GNs) are employed to more accurately express uncertainty of the evaluation objects. Firstly, operations and comparison method for interval grey numbers are defined. Subsequently, the interval grey number normalized weighted geometric Bonferroni mean (GNWGBM) operator, is presented accordingly in some desirable characteristics.

Key words*: Interval Grey numbers (GNs), Bonferroni mean, Dombi norms, Multi-criteria decision Making, MCDM.*

1 INTRODUCTION

In second half of 20th century, multi-criteria decision making (MCDM) process has emerged as fastest growing sector in management science domain at finding the best option from all of the feasible alternatives based on inconsistent criteria [1]. But in imprecise based real life decision problems in various fields as engineering, economics, and management, decision experts have incomplete and inconsistent information about alternatives with respect to conflicting attributes [2]. Considering the complexity and uncertainty of MCDM process, decision makers (DMs) may not be able to express their evaluations in precise numbers, but provide some approximate form with their knowledge and perception [3]. Thus to deal with it, Deng [4] introduced the grey system theory but no satisfactory result is drawn from it. While term "fuzzy" involve uncertain factors in the evaluation information caused by the impreciseness of human thinking, "grey" denote objective uncertainty due to insufficient and incomplete information [5]. Grey system theory is one of the new mathematical approaches born from the concept of the grey sets [3]. As the basic element of grey system, a grey number is a real number in fact while the precise value could not be determined but the potential range of values can be defined. So a grey number is represented as a set of potential discrete, continuous or mixed values [6].

Generally, aggregation operators are important tools for fusing information in multi-criteria decision making (MCDM) problems. The most widely used operators in fuzzy theory are the min and the max operator. However, in the case of min-max operators, the main disadvantage is that the result is determined only by one variable and the other has no influence. Also, the min-max operators are not analytic, their second derivative is not continuous [7]. These disadvantages of traditional min-max operators in fuzzy environment are successfully eliminated by generalized Dombi operator class. Also, Dombi T-norms (TN) and T-conorms (TCN) have general parameters of general TN and TCN, and this can make the aggregation process more flexible. Making decisions in real systems requires rational understanding of the relationship between attributes and elimination of the impact of awkward data. For this purpose, Bonferroni [8] introduced the Bonferroni mean (BM) operator, allowing the presentation of interconnections between elements and their fusion into unique score function. Obviously, Bonferroni and Dombi aggregators can successfully achieve this goal. According to the author's knowledge, there has been no research up to date considering the fusion of the Dombi and Bonferroni aggregators in interval grey environment represented by interval grey numbers (GNs). Therefore, logical goal and motivation for this study is to show hybrid Dombi-Bonferroni aggregator for the transformation by GNs.

The remainder of this paper is structured as follows: the second section of the paper shows the basic settings of GN, arithmetic operations with GN and mathematical presentation of Dobmi i Bonferroni aggregators. The third section of the paper presents a novel hybrid GNNWDBM aggregator and its application.

2 PRELIMINARIES

1.1. Operations on Interval Grey Numbers

Definition 6. Grey number operation is a special operation defined on sets of intervals. In analog to the real numbers, arithmetic operations between two grey numbers $\otimes\Upsilon_1=[\underline{\Upsilon}_1,\overline{\Upsilon}_1]$ and $\otimes\Upsilon_2=[\underline{\Upsilon}_2,\overline{\Upsilon}_2]$ are defined by the following expressions [4]:

(1) Adding of grey numbers "+"

$$\otimes\Upsilon_1+\otimes\Upsilon_2=[\underline{\Upsilon}_1,\overline{\Upsilon}_1]+[\underline{\Upsilon}_2,\overline{\Upsilon}_2]=[\underline{\Upsilon}_1+\underline{\Upsilon}_2,\overline{\Upsilon}_1+\overline{\Upsilon}_2] \qquad (2)$$

(2) Subtraction of grey numbers " – "

$$\otimes\Upsilon_1-\otimes\Upsilon_2=[\underline{\Upsilon}_1,\overline{\Upsilon}_1]-[\underline{\Upsilon}_2,\overline{\Upsilon}_2]=[\underline{\Upsilon}_1-\overline{\Upsilon}_2,\overline{\Upsilon}_1-\underline{\Upsilon}_2] \quad (3)$$

(2) Multiplication of grey numbers "×"

$$\otimes\Upsilon_1\times\otimes\Upsilon_2=[\underline{\Upsilon}_1,\overline{\Upsilon}_1]\times[\underline{\Upsilon}_2,\overline{\Upsilon}_2] =\begin{bmatrix}\min\left\{\underline{\Upsilon}_1\underline{\Upsilon}_2,\underline{\Upsilon}_1\overline{\Upsilon}_2,\overline{\Upsilon}_1\underline{\Upsilon}_2,\overline{\Upsilon}_1\overline{\Upsilon}_2\right\},\\ \max\left\{\underline{\Upsilon}_1\underline{\Upsilon}_2,\underline{\Upsilon}_1\overline{\Upsilon}_2,\overline{\Upsilon}_1\underline{\Upsilon}_2,\overline{\Upsilon}_1\overline{\Upsilon}_2\right\}\end{bmatrix} \quad (4)$$

(4) Division of grey numbers "/"

$$\otimes\Upsilon_1\div\otimes\Upsilon_2=[\underline{\Upsilon}_1,\overline{\Upsilon}_1]\times\left[\frac{1}{\overline{\Upsilon}_2},\frac{1}{\underline{\Upsilon}_2}\right],\ \otimes\Upsilon_2\notin 0 \quad (5)$$

(5) The n^{th} root of grey $\otimes\Upsilon$

$$(\otimes\Upsilon)^{1/n}=\left[(\underline{\Upsilon})^{1/n},(\overline{\Upsilon})^{1/n}\right] \quad (6)$$

Example 2. If we assume that $\otimes\Upsilon_1\in[3,5]$ and $\otimes\Upsilon_2\in[2,6]$ are two interval grey numbers and n=2, then we can show that:

$$\otimes\Upsilon_1+\otimes\Upsilon_2=[3,5]+[2,6]=[5,11]$$

$$\otimes\Upsilon_1-\otimes\Upsilon_2=[3,5]-[2,6]=[-3,3]$$

$$\otimes\Upsilon_1\times\otimes\Upsilon_2=[3,5]\times[2,6]=\begin{bmatrix}\min\{6,18,10,30\},\\ \max\{6,18,10,30\}\end{bmatrix}=[6,30]$$

$$\otimes\Upsilon_1\div\otimes\Upsilon_2=[3,5]\times\left[\frac{1}{6},\frac{1}{2}\right]=\begin{bmatrix}\min\left\{\frac{3}{6},\frac{3}{2},\frac{5}{6},\frac{5}{2}\right\},\\ \max\left\{\frac{3}{6},\frac{3}{2},\frac{5}{6},\frac{5}{2}\right\}\end{bmatrix}=[0.5,2.5]$$

$$(\otimes\Upsilon_1)^{1/2}=\left[(3)^{1/2},(5)^{1/2}\right]=[1.73,2.24]$$

1.2. Bonferroni mean operator

Definition 1 [8]: Let $(a_1,a_2,...,a_n)$ be a set of non-negative numbers and $p,q\ \geq 0$. If

$$BM^{p,q}(a_1,a_2,...,a_n)=\left(\frac{1}{n(n-1)}\sum_{\substack{i,j=1\\ i\neq j}}^{n}a_i^p a_j^q\right)^{\frac{1}{p+q}} \quad (2)$$

then $BM^{p,q}$ is called a Bonferroni mean (BM) operator.

Definition 4 [9]: Let $(a_1,a_2,...,a_n)$ be a set of non-negative numbers and $p,q \geq 0$. If

$$NWGBM^{p,q}(a_1,a_2,...,a_n)=\frac{1}{p+q}\prod_{i,j=1}^{n}\left(pa_i+qa_j\right)^{\frac{w_iw_j}{1-w_i}} \quad (5)$$

Then $NWGBM^{p,q}$ is called a normalized weighted geometric BM (NWGBM) operator.

1.3. Dombi operations of GN

Definition 2. Let p and q be any two real numbers. Then, the Dombi T-norm and T-conorm between p and q are defined as follows [7]:

$$O_D(p,q)=\frac{1}{1+\left\{\left(\frac{1-p}{p}\right)^{\rho}+\left(\frac{1-q}{q}\right)^{\rho}\right\}^{1/\rho}} \quad (1)$$

$$O_D^c(p,q)=1-\frac{1}{1+\left\{\left(\frac{p}{1-p}\right)^{\rho}+\left(\frac{q}{1-q}\right)^{\rho}\right\}^{1/\rho}} \quad (2)$$

where $\rho>0$ and $(p,q)\in[0,1]$.

According to the Dombi T-norm i T-conorm, we define the Dombi operations of grey numbers (GN).

Definition 3. Suppose $\otimes\varphi_1=[\underline{\varphi}_1,\overline{\varphi}_1]$ and $\otimes\varphi_2=[\underline{\varphi}_2,\overline{\varphi}_2]$ are two GN, $\rho,\gamma>0$ and let it be $f(\otimes\varphi_i)=\left[f(\underline{\varphi}_i),f(\overline{\varphi}_i)\right]=\left[\frac{\underline{\varphi}_i}{\sum_{i=1}^{n}\underline{\varphi}},\frac{\overline{\varphi}_i}{\sum_{i=1}^{n}\overline{\varphi}_i}\right]$ grey function, then some operational lows of grey numbers based on the Dombi T-norm and T-conorm can be defined as follows

(1) Addition "+"

$$\otimes\varphi_1+\otimes\varphi_2=\begin{bmatrix}\sum_{j=1}^{2}\underline{\varphi}_j-\frac{\sum_{j=1}^{2}\underline{\varphi}_j}{1+\left\{\left(\frac{f(\underline{\varphi}_1)}{1-f(\underline{\varphi}_1)}\right)^{\rho}+\left(\frac{f(\underline{\varphi}_2)}{1-f(\underline{\varphi}_2)}\right)^{\rho}\right\}^{1/\rho}},\\ \sum_{j=1}^{2}\overline{\varphi}_j-\frac{\sum_{j=1}^{2}\overline{\varphi}_j}{1+\left\{\left(\frac{f(\overline{\varphi}_1)}{1-f(\overline{\varphi}_1)}\right)^{\rho}+\left(\frac{f(\overline{\varphi}_2)}{1-f(\overline{\varphi}_2)}\right)^{\rho}\right\}^{1/\rho}}\end{bmatrix} \quad (3)$$

(2) Multiplication "×"

$$\otimes\varphi_1\times\otimes\varphi_2=\begin{bmatrix}\frac{\sum_{j=1}^{2}\underline{\varphi}_j}{1+\left\{\left(\frac{1-f(\underline{\varphi}_1)}{f(\underline{\varphi}_1)}\right)^{\rho}+\left(\frac{1-f(\underline{\varphi}_2)}{f(\underline{\varphi}_2)}\right)^{\rho}\right\}^{1/\rho}},\\ \frac{\sum_{j=1}^{2}\overline{\varphi}_j}{1+\left\{\left(\frac{1-f(\overline{\varphi}_1)}{f(\overline{\varphi}_1)}\right)^{\rho}+\left(\frac{1-f(\overline{\varphi}_2)}{f(\overline{\varphi}_2)}\right)^{\rho}\right\}^{1/\rho}}\end{bmatrix} \quad (4)$$

(3) Scalar multiplication, where $\gamma>0$

$$\gamma\otimes\varphi_1=\left[\underline{\varphi}_1-\frac{\underline{\varphi}_1}{1+\left\{\gamma\left(\frac{\underline{\varphi}_1}{1-\underline{\varphi}_1}\right)^{\rho}\right\}^{1/\rho}},\underline{\varphi}_1-\frac{\overline{\varphi}_1}{1+\left\{\gamma\left(\frac{\overline{\varphi}_1}{1-\overline{\varphi}_1}\right)^{\rho}\right\}^{1/\rho}}\right] \quad (5)$$

(4) Power, where $\gamma>0$

$$\{\otimes\varphi_1\}^{\gamma}=\left[\frac{\underline{\varphi}_1}{1+\left\{\gamma\left(\frac{1-\underline{\varphi}_1}{\underline{\varphi}_1}\right)^{\rho}\right\}^{1/\rho}},\frac{\overline{\varphi}_1}{1+\left\{\gamma\left(\frac{1-\overline{\varphi}_1}{\overline{\varphi}_1}\right)^{\rho}\right\}^{1/\rho}}\right] \quad (6)$$

3 NORMALIZED WEIGHTED GEOMETRIC DOMBI BONFERONI MEAN OPERATOR WITH GREY NUMBERS

Based on the GN operators (3)-(6) we propose the GN Normalized Weighted Dombi Bonferroni mean (GNNWDBM) operator.

Theorem 1. Let it be $\otimes a_j=[\underline{a}_j,\bar{a}_j]$; $(j=1,2,...,n)$, collection of GNs in *R*, then GNNWDBM operator is defined as follows

$$GNNWDBM^{p,q,\rho}(\otimes a_1,\otimes a_2,...,\otimes a_n)=$$

$$=\frac{1}{p+q}\prod_{i,j=1}^{n}\left(p\otimes a_i+q\otimes a_j\right)^{\frac{w_iw_j}{1-w_i}}$$

$$=\left[\begin{array}{c}\sum_{i=1}^{n}\underline{a}_i-\frac{\sum_{i=1}^{n}\underline{a}_i}{\left(1+\left\{\frac{1}{(p+q)w_iw_j}\frac{1-w_i}{\sum_{\substack{i,j=1\\ i\neq j}}^{n}\left(\frac{1}{p\left(\frac{f(\underline{a}_i)}{1-f(\underline{a}_i)}\right)^{\rho}+q\left(\frac{f(\underline{a}_j)}{1-f(\underline{a}_j)}\right)^{\rho}}\right)}\right\}\right)^{1/\rho}},\\ \sum_{i=1}^{n}\bar{a}_i-\frac{\sum_{i=1}^{n}\bar{a}_i}{\left(1+\left\{\frac{1}{(p+q)w_iw_j}\frac{1-w_i}{\sum_{\substack{i,j=1\\ i\neq j}}^{n}\left(\frac{1}{p\left(\frac{f(\bar{a}_i)}{1-f(\bar{a}_i)}\right)^{\rho}+q\left(\frac{f(\bar{a}_j)}{1-f(\bar{a}_j)}\right)^{\rho}}\right)}\right\}\right)^{1/\rho}}\end{array}\right]$$

where $f(\otimes a_i)=\left(f(\underline{a}_i),f(\bar{a}_i)\right)=\left(\frac{\underline{a}_i}{\sum_{i=1}^{n}\underline{a}_i},\frac{\bar{a}_i}{\sum_{i=1}^{n}\bar{a}_i}\right)$ represents grey function.

Proof: We need to prove the Eq. (7) is kept. According to the operational laws of GNs, we get

$$pa_i=\left[\underline{a}_i-\frac{\underline{a}_i}{p\left(\frac{f(\underline{a}_i)}{1-f(\underline{a}_i)}\right)^{1/\rho}},\bar{a}_i-\frac{\bar{a}_i}{p\left(\frac{f(\bar{a}_i)}{1-f(\bar{a}_i)}\right)^{1/\rho}}\right],$$

$$qa_i=\left[\underline{a}_i-\frac{\underline{a}_i}{q\left(\frac{f(\underline{a}_i)}{1-f(\underline{a}_i)}\right)^{1/\rho}},\bar{a}_i-\frac{\bar{a}_i}{q\left(\frac{f(\bar{a}_i)}{1-f(\bar{a}_i)}\right)^{1/\rho}}\right]$$ and

$$p\otimes a_i+\otimes a_j=\left(\begin{array}{c}\underline{a}_i+\underline{a}_j-\frac{\underline{a}_i+\underline{a}_j}{\left(1+\left\{p\left(\frac{f(\underline{a}_i)}{1-f(\underline{a}_i)}\right)^{\rho}+q\left(\frac{f(\underline{a}_j)}{1-f(\underline{a}_j)}\right)^{\rho}\right\}\right)^{1/\rho}},\\ \bar{a}_i+\bar{a}_j-\frac{\bar{a}_i+\bar{a}_j}{\left(1+\left\{p\left(\frac{f(\bar{a}_i)}{1-f(\bar{a}_i)}\right)^{\rho}+q\left(\frac{f(\bar{a}_j)}{1-f(\bar{a}_j)}\right)^{\rho}\right\}\right)^{1/\rho}}\end{array}\right)$$

further we get

$$\left(p\otimes a_i+\otimes a_j\right)^{\frac{w_iw_j}{1-w_i}}=\left(\begin{array}{c}\frac{\underline{a}_i+\underline{a}_j}{\left(1+\left\{\frac{1}{1-w_i}\frac{w_iw_j}{p\left(\frac{1-f(\underline{a}_i)}{f(\underline{a}_i)}\right)^{\rho}+q\left(\frac{1-f(\underline{a}_j)}{f(\underline{a}_j)}\right)^{\rho}}\right\}\right)^{1/\rho}},\\ \frac{\bar{a}_i+\bar{a}_j}{\left(1+\left\{\frac{1}{1-w_i}\frac{w_iw_j}{p\left(\frac{1-f(\bar{a}_i)}{f(\bar{a}_i)}\right)^{\rho}+q\left(\frac{1-f(\bar{a}_j)}{f(\bar{a}_j)}\right)^{\rho}}\right\}\right)^{1/\rho}}\end{array}\right)$$

Thereafter,

$$\prod_{\substack{i,j=1\\ i\neq j}}^{n}\left(p\otimes a_i+\otimes a_j\right)^{\frac{w_iw_j}{1-w_i}}=\left(\begin{array}{c}\frac{\sum_{i=1}^{n}\underline{a}_i}{\left(1+\left\{\frac{w_iw_j}{1-w_i}\sum_{\substack{i,j=1\\ i\neq j}}^{n}\left(\frac{1}{p\left(\frac{1-f(\underline{a}_i)}{f(\underline{a}_i)}\right)^{\rho}+q\left(\frac{1-f(\underline{a}_j)}{f(\underline{a}_j)}\right)^{\rho}}\right)\right\}\right)^{1/\rho}},\\ \frac{\sum_{i=1}^{n}\bar{a}_i}{\left(1+\left\{\frac{w_iw_j}{1-w_i}\sum_{\substack{i,j=1\\ i\neq j}}^{n}\left(\frac{1}{p\left(\frac{1-f(\bar{a}_i)}{f(\bar{a}_i)}\right)^{\rho}+q\left(\frac{1-f(\bar{a}_j)}{f(\bar{a}_j)}\right)^{\rho}}\right)\right\}\right)^{1/\rho}},\end{array}\right)\quad(7)$$

Therefore,

$$GNNWDBM^{p,q,\rho}(\otimes a_1,\otimes a_2,...,\otimes a_n)=\frac{1}{p+q}\prod_{i,j=1}^{n}\left(p\otimes a_i+q\otimes a_j\right)^{\frac{w_iw_j}{1-w_i}}$$

$$=\left[\begin{array}{c}\sum_{i=1}^{n}\underline{a}_i-\frac{\sum_{i=1}^{n}\underline{a}_i}{\left(1+\left\{\frac{1}{(p+q)w_iw_j}\frac{1-w_i}{\sum_{\substack{i,j=1\\ i\neq j}}^{n}\left(\frac{1}{p\left(\frac{f(\underline{a}_i)}{1-f(\underline{a}_i)}\right)^{\rho}+q\left(\frac{f(\underline{a}_j)}{1-f(\underline{a}_j)}\right)^{\rho}}\right)}\right\}\right)^{1/\rho}},\\ \sum_{i=1}^{n}\bar{a}_i-\frac{\sum_{i=1}^{n}\bar{a}_i}{\left(1+\left\{\frac{1}{(p+q)w_iw_j}\frac{1-w_i}{\sum_{\substack{i,j=1\\ i\neq j}}^{n}\left(\frac{1}{p\left(\frac{f(\bar{a}_i)}{1-f(\bar{a}_i)}\right)^{\rho}+q\left(\frac{f(\bar{a}_j)}{1-f(\bar{a}_j)}\right)^{\rho}}\right)}\right\}\right)^{1/\rho}}\end{array}\right]$$

Theorem 2 (Idempotency): Let it be $\otimes a_j=[\underline{a}_j,\bar{a}_j]$; $(j=1,2,...,n)$, collection of GNs in *R*, then, if $\otimes a_i=\otimes a$, then

$$GNNWDBM^{p,q,\rho}(\otimes a_1,\otimes a_2,..,\otimes a_n)=GNNWDBM^{p,q,\rho}(\otimes a,\otimes a,..,\otimes a)$$
.

Proof: Since $\otimes a_i=\otimes a$, i.e. $\underline{a}_i=\underline{a}$, $\bar{a}_i=\bar{a}$ then

$$GNNWDBM^{p=1,q=1,\rho=1}(\otimes a_1,\otimes a_2,...,\otimes a_n)=(\otimes a,\otimes a,...,\otimes a)$$

$$=\left(\frac{\sum_{i=1}^{n}\underline{a}_i}{1+\left\{\frac{1}{p+q}\frac{n(n-1)}{\sum_{\substack{i,j=1\\i\neq j}}^{n}\frac{1}{\left(p\left(\frac{1-f(\underline{a}_i)}{f(\underline{a}_i)}\right)^{\rho}+q\left(\frac{1-f(\underline{a}_j)}{f(\underline{a}_j)}\right)^{\rho}\right)}}\right\}^{1/\rho}},\frac{\sum_{i=1}^{n}\overline{a}_i}{1+\left\{\frac{1}{p+q}\frac{n(n-1)}{\sum_{\substack{i,j=1\\i\neq j}}^{n}\frac{1}{\left(p\left(\frac{1-f(\overline{a}_i)}{f(\overline{a}_i)}\right)^{\rho}+q\left(\frac{1-f(\overline{a}_j)}{f(\overline{a}_j)}\right)^{\rho}\right)}}\right\}^{1/\rho}}\right)$$

$$=\left(\frac{2\underline{a}_i}{1+\left\{\frac{1}{1+1}\frac{2}{\sum_{i=1}^{n}\frac{1}{\left(\left(\frac{1-f(\underline{a}_i)}{f(\underline{a}_i)}\right)^{\rho}+\left(\frac{1-f(\underline{a}_j)}{f(\underline{a}_j)}\right)^{\rho}\right)}}\right\}^{1/\rho}},\frac{2\overline{a}_i}{1+\left\{\frac{1}{1+1}\frac{2}{\sum_{i=1}^{n}\frac{1}{\left(\left(\frac{1-f(\overline{a}_i)}{f(\overline{a}_i)}\right)^{\rho}+\left(\frac{1-f(\overline{a}_j)}{f(\overline{a}_J)}\right)^{\rho}\right)}}\right\}^{1/\rho}}\right)$$

$$=\left(\frac{2\underline{a}_i}{1+\left\{\frac{1}{\sum_{i=1}^{n}\frac{1}{\left((1+1)\left(\frac{1-f(\underline{a}_i)}{f(\underline{a}_i)}\right)^{\rho}\right)}}\right\}^{1/\rho}},\frac{2\overline{a}_i}{1+\left\{\frac{1}{\sum_{i=1}^{n}\frac{1}{\left((1+1)\left(\frac{1-f(\overline{a}_i)}{f(\overline{a}_i)}\right)^{\rho}\right)}}\right\}^{1/\rho}}\right)=\left(\underline{a}_i,\overline{a}_i\right)=\otimes a$$

The proof of *Theorem 2* is completed.

Theorem 3 (Boundedness): Let it be $\otimes a_j=[\underline{a}_j,\overline{a}_j]$; $(j=1,2,...,n)$, collection of GNs in *R,* let $\otimes a^-=\left(\min\underline{a}_j,\min\overline{a}_j\right)$ and $\otimes a^+=\left(\max\underline{a}_j,\max\overline{a}_j\right)$ then

$\otimes a^-\leq GNNWDBM^{p,q,\rho}(\otimes a_1,\otimes a_2,...,\otimes a_n)\leq\otimes a^+$.

Proof: Let $\otimes a^-=\min(\otimes a_1,\otimes a_2,...,\otimes a_n)=\left(\min\underline{a}_j,\min\overline{a}_j\right)$ and $\otimes a^+=\max(\otimes a_1,\otimes a_2,...,\otimes a_n)=\left(\max\underline{a}_j,\max\overline{a}_j\right)$. Then, it can be stated that $\underline{a}^-=\min_j(\underline{a}_j)$, $\overline{a}^-=\min_j(\overline{a}_j)$, $\underline{a}^+=\max_j(\underline{a}_j)$ and $\overline{a}^+=\max_j(\overline{a}_j)$. Based on that, the following inequalities can be formulated:

$\otimes a^-\leq\otimes a_j\leq\otimes a^+;\min_j(\underline{a}_j)\leq\underline{a}_j\leq\max_j(\underline{a}_j);$

$\min_j(\overline{a}_j)\leq\overline{a}_j\leq\max_j(\overline{a}_j);$

According to the inequalities shown above, it can be concluded that $\otimes a^-\leq GNNWDBM^{p,q,\rho}(\otimes a_1,\otimes a_2,...,\otimes a_n)\leq\otimes a^+$ holds.

Theorem 4 (Commutativity): Let the grey set $(\otimes a_1',\otimes a_2',...,\otimes a_n')$ be any permutation of $(\otimes a_1,\otimes a_2,..,\otimes a_n)$.

Then $GNNWDBM^{p,q,\rho}(\otimes a_1,\otimes a_2,..,\otimes a_n)=GNNWDBM^{p,q,\rho}(\otimes a_1',\otimes a_2',...,\otimes a_n')$.

Proof: This property is obvious.

Example. While buying a car, the buyer applies four criteria for the evaluation of the alternative (the car): Quality (*C1*), Price (*C2*), Safety (*C3*) and Comfort (*C4*). The criteria for alternative A1 are presented with interval grey numbers $\otimes a_1=[2,4]$, $\otimes a_2=[3,5]$, $\otimes a_3=[3,5]$ and $\otimes a_4=[2,4]$, $p=q=\rho=1$ and $w_j=(0.18,0.32,0.33,0.17)$. Then, by application of GNNWDBM we can obtain utility function for alternative A1 as follows:

Similarly we can obtain utility functions of other alternatives from the set of alternatives $A_i=(A_1,A_2,...,A_m)$, where *m* represents number of alternatives in the set A_i.

4 CONCLUSION

Many real-world decision making problems are related with uncertainties and/or some form of predictions and therefore their solutions can be much better determined using an extended MCDM method which is adapted for the use of

$$GNNWDBM_w^{1,1,1}\{[2,4];[3,5];[3,5];[2,4]\}=$$

$$=\left[\begin{array}{l}10-\dfrac{2+3+3+4}{1+\left\{\frac{1}{1+1}\frac{1}{\frac{0.18\cdot0.32}{1-0.18}\frac{1}{0.25^1+0.43^1}+\frac{0.18\cdot0.33}{1-0.18}\frac{1}{0.25^1+0.43^1}+\frac{0.18\cdot0.17}{1-0.18}\frac{1}{0.25^1+0.25^1}+\frac{0.32\cdot0.18}{1-0.32}\frac{1}{0.43^1+0.25^1}+\frac{0.32\cdot0.33}{1-0.32}\frac{1}{0.43^1+0.43^1}+...+\frac{0.17\cdot0.33}{1-0.17}\frac{1}{0.25^1+0.43^1}}\right\}^{1/1}},\\ 18-\dfrac{4+5+5+4}{1+\left\{\frac{1}{1+1}\frac{1}{\frac{0.18\cdot0.32}{1-0.18}\frac{1}{0.22^1+0.278^1}+\frac{0.18\cdot0.33}{1-0.18}\frac{1}{0.22^1+0.278^1}+\frac{0.18\cdot0.17}{1-0.18}\frac{1}{0.22^1+0.22^1}+\frac{0.32\cdot0.18}{1-0.32}\frac{1}{0.278^1+0.22^1}+\frac{0.32\cdot0.33}{1-0.32}\frac{1}{0.278^1+0.278^1}+...+\frac{0.17\cdot0.33}{1-0.17}\frac{1}{0.22^1+0.278^1}}\right\}^{1/1}}\end{array}\right]$$

$$=\left[2.61,4.61\right]$$

fuzzy or interval grey numbers. For practical problems, interval grey numbers can better express the diversified and utilized information that affect the rationality of decision results. GNs can flexibly express uncertain, imprecise and inconsistent information that widely exist in real-life situations. The operation and ranking method for interval grey numbers plays a vital role in development of grey system theory. Using the kernel and the degree of greyness of interval grey number, we propose aggregation operator namely GNNWDBM operator for solving MCDM problems. The usability and effectiveness of the proposed approach are checked by the numerical illustration and final results of the methodology is observable in result discussion section.

In future, we expect to investigate the generalized distance measures and aggregation operators of IGNs. Further integration of the interval grey number approach into existing MCDM models [10-12] would make a significant contribution to deal with both uncertainty and subjectivity in the decision making process.

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Contact address:
Dragan Pamučar
University of defence in Belgrade
Military academy, Department of logistics,
11000 Belgrade
E-mail: dragan.pamucar@va.mod.gov.rs

UNIVERSITY OF NIS FACULTY OF MECHANICAL ENGINEERING

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SUPPLIER SELECTION FOR DISTRIBUTION OF FINISHED PRODUCTS: COMBINED FUCOM-MABAC MODEL

Ţeljko STEVIĆ[1]
Branislavka MIČIĆ[1]
Dominik LUKIĆ[1]
Milovan TOMAŠEVIĆ[2]
Siniša SREMAC[3]

[1)]University of East Sarajevo, Faculty of Transport and Traffic EngineeringDoboj, Bosnia and Herzegovina
[2)]Faculty of Information Studies in Novo Mesto, Slovenia
[3)]Faculty of Technical Sciences, University of Novi Sad, Serbia

Abstract

Suplier selection is an issue of a great importance for the functioning of the entire supply chain. The task that is performed in most of the researches is the supplier selection of materials that are involved in the production process, in order to create a finished product. In this paper thesituation is differentbecause of there is a supplier selection of finished products for the distribution phase. The research was carried out for the "Napredak promet"doo Companyanditwasbased on nine criteria. An expert team was formed to evaluate the criteria and potential suppliers. The significance of the criteria was determined using the Full consistency method (FUCOM), while the Multi Attributive Border Approximation area Comparison (MABAC) was used to rank potential suppliers. The results were verified through the sensitivity analysis and comparison with other multi-criteria decision-making methods.

Keywords:*supplier selection, distribution, MCDM, MABAC, FUCOM*

1. INTRODUCTION

The stages of product creation rang from the procurement of raw materials from suppliers, the production of semi-finished products and parts, to the assembly of the final product.Its deliveries to the end-user in modern logistics take place as interdependent processes, which can be called the supply chain. According toStević [20] „Modern supply chains need to meet strict requirements, so the decision makers find it very difficult to choose the right evaluation for the potential suppliers. This will ensure efficient production and final price formation which will be competitive on the market.". The goal of each company is to ensure market existence. This goal can sometimes be difficult to achieve because the competition is large in the market and only companies that success to find the best ratio between price and quality survive. The quality of the products depends on the quality of the raw materials sourced from the suppliers.According to Rajesh and Ravi [19]:Suppliers can be considered as inevitable sources of external risks in modern supply chains.In order to minimize the existing risk before the supplier selection, the company must define the criteria that suppliers should meet.

As Kannan et al. [8] assert in their research:The supplier selection problem involves several quantitative and qualitative criteria. In the supplier selection process, if suppliers have limited capacity or other constraints, it is necessary to determine the best supplier and order quantity of each supplier.Given that there are a large number of criteria that need to be combined into one model, the area of multi-criteria decision making (MCDM) is often applied. Thanks to its methods, this area enables the integration of different criteria into a single model and their evaluation.As the authors indicate in their research [1]: By applying multi-criteria decision-making methods, it is possible to select adequate strategies, rationalize certain logistics and other processes, and make appropriate decisions that affect the company's business or their subsystems. When using these methods it should be emphasized that there is also a certain degree of the subjectivity of the decision-maker. In research authors state [13]:Determining the relative criteria weights in multi-criteria decision-making models is always a specific problem inevitably accompanied by subjectivity. This process is very important and has a significant impacton the final decision-making result since the weight coefficients in some methods crucially influence the solution.Subjectivity can be minimized by using the FUCOM method, as is the case in this paper.When it comes to the application of the VKO method, most of the research concerns the selection of raw materials for production. Specific to this paper is that the MCDM methods are applied in the supplier selection of finished products that are further delivered to the end customer.

2. METHOD

As mentioned earlier in this paper, the FUCOM and MABAC methods were applied whose algorithms are shown below.

2.1. Full Consistency Method (FUCOM)

So far this method is used in many different research [1-3],[4, 5], [11],[18]. This method enables the precise determination of the values of the weight coefficients of all of the elements mutually compared at a certain level of the hierarchy, simultaneously satisfying the conditions of the comparison consistency, too.FUCOM provides the ability to validate the model by calculating the error value for the obtained weight vectors by determining DFC. On the other hand, in the other models for determining the weights of criteria (the BWM, the AHP models), the redundancy of the pairwise comparison appears, which makes them less vulnerable to errors in judgment, while the FUCOM methodological procedure eliminates this problem. [17]

Step 1. In the first step, the criteria from the predefined set of the evaluation criteria are ranked. The ranking is performed according to thesignificance of the criteria, i.e. starting from the criterion which is expected to have the highest weight coefficient to the criterion of the least significance. Thus, the criteria ranked according to the expected valuesof the weight coefficients are obtained [16]:

$$C_{j(1)} > C_{j(2)} > \cdots > C_{j(k)} \quad (1)$$

Step 2. In the second step, a comparison of the ranked criteria is carried out and the comparative priority ($\varphi_{k/(k+1)}, k = 1,2,\ldots,n$;where$k$ presents the rank of the criteria) of the evaluationcriteria is determined:

$$\varphi = (\varphi_{1/2}, \varphi_{2/3}, \ldots, \varphi_{k(k+1)}) \quad (2)$$

Step 3. In the third step, the final values of the weight coefficients of the evaluation criteria are calculated:

$$\left|\frac{W_{j(k)}}{W_{j(k+1)}} - \varphi_{k/(k+1)}\right| \le X; \forall j$$
$$\left|\frac{W_{j(k)}}{W_{j(k+2)}} - \varphi_{k/(k+1)} \otimes \varphi_{(k+1)/(k+2)}\right| \le X; \forall j$$
$$\sum_{j=1}^{n} W_j = 1, \forall j \quad (5)$$
$$W_j \ge 0, \forall j$$

2.2. Multi Attributive Border Approximation area Comparison (MABAC)

The MABAC Method was developed by Pamučar and Ćirović [14] and was first presented to the scientific public in 2015. To date, it has found very wide application and modifications solving numerous problems in the field of multi-criteria decision-making. [12, 13],[15],[21].

The basis of the MABAC method is seen in the definition of the distance of the criterion function of each alternative from the border approximation area. The next section shows the process of implementing the MABAC method, consisting of 6 steps [14]:

Step 1. Formation of the initial decision matrix (X).

$$X = \begin{matrix} A_1 \\ A_2 \\ \cdots \\ A_m \end{matrix} \overset{\begin{matrix} C_1 & C_2 & \cdots & C_n \end{matrix}}{\begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ x_{m1} & x_{m2} & \cdots & x_{mm} \end{bmatrix}} \quad (6)$$

*Step 2.*Normalization of the elements from the initial matrix (X).

$$T_r = \begin{matrix} A_1 \\ A_2 \\ \cdots \\ A_m \end{matrix} \overset{\begin{matrix} C_1 & C_2 & \cdots & C_n \end{matrix}}{\begin{bmatrix} t_{r11} & t_{r12} & \cdots & t_{r1n} \\ t_{r21} & t_{r22} & \cdots & t_{r2n} \\ \cdots & \cdots & \cdots & \cdots \\ t_{rm1} & t_{rm2} & \cdots & t_{rmn} \end{bmatrix}} \quad (7)$$

Step 3. Calculation of the elements from the weighted matrix (V).

$$V_{ij} = w_i \cdot t_{ij} + w_i \quad (8)$$

*Step 4.*Determining the border approximation area matrix (G).

$$g_i = \left(\prod_{j=1}^{m} V_{ij}\right)^{1/m} \quad (9)$$

Step 5. Calculation of the distance of the alternative for the border approximation area from the matrix elements (Q).

$$Q = V - G \quad (10)$$

Step 6. Ranking the alternatives.

$$S_i = \sum_{j=1}^{n} q_{ij}, j = 1,2,\ldots n, i = 1,2,\ldots,m. \quad (11)$$

3. SUPPLIER SELECTION FOR DISTRIBUTION OF FINISHED PRODUCTS: COMBINED FUCOM-MABAC MODEL

The research was carried out for the "Napredakpromet" doo Companylocated in Žepče. The types of building materials this company has on offer are: tile, cement, powder materials, silicones, grout and iron. In this paper, tile suppliers are analyzed. The analysis of the above suppliers was performed using the FUCOM and MABAC methods. FUCOM method is applied for determining criteria weights for nine. The obtained results were further used in the MABAC method, which ranked the tile alternatives (suppliers).

Table 1. Assessment of criteria by decision makers

	Criterion	DM_1	DM_2	DM_3
C_1	Quality	1	1	3
C_2	Price	3	2	1
C_3	Delivery time	4	3	6
C_4	Warranty	2	4	2
C_5	Reputation	5	6	8
C_6	Reliability	6	5	9
C_7	Volume discount	8	9	4
C_8	Payment method	9	7	5
C_9	Certification	7	8	7

Table 1 shows the assessment of suppliers by the decision-makers, that is, the personnel in charge of organizing the supply process at the company „Napredakpromet" d.o.o. Based on the presented data, the FUCOM method is applied. The first step of this method, i.e the ranking of criteria from a predefined set ofcriteria, is shown in Table 4.

Table 4. Evaluation of criteria by DMs

	DM$_1$								
Criteria	C_1	C_4	C_2	C_3	C_5	C_6	C_9	C_7	C_8
$W_j(k)$	1	1.3	1.8	2.0	2.2	2.4	2.7	3.3	3.5
	DM$_2$								
Criteria	C_1	C_2	C_3	C_4	C_6	C_5	C_8	C_9	C_7
$W_j(k)$	1	1.1	1.5	1.6	1.9	2.0	2.6	3.1	3.2
	DM$_3$								
Criteria	C_2	C_4	C_1	C_7	C_8	C	C_9	C_5	C_6
$W_j(k)$	1	1.1	1.2	1.4	1.9	2.2	2.4	2.7	3.0

In the second step of the FUCOM method, the ranking criteria are compared:

$\varphi_{C1/C4} = C_4/C_1 = 1.3/1 = 1.3$
$\varphi_{C4/C2} = C_2/C_4 = 1.8/1.3 = 1.38$
$\varphi_{C2/C3} = C_3/C_2 = 2.0/1.8 = 1.11$
$\varphi_{C3/C5} = C_5/C_3 = 2.2/2.0 = 1.1$
$\varphi_{C5/C6} = C_6/C_5 = 2.4/2.2 = 1.09$
$\varphi_{C6/C9} = C_9/C_6 = 2.7/2.4 = 1.125$
$\varphi_{C9/C7} = C_7/C_9 = 3.3/2.7 = 1.22$
$\varphi_{C7/C8} = C_8/C_7 = 3.5/3.3 = 1.06$

$\varphi_{C1/C2} = C_2/C_1 = 1.1/1 = 1.1$
$\varphi_{C2/C3} = C_3/C_2 = 1.5/1.1 = 1.364$
$\varphi_{C3/C4} = C_4/C_3 = 1.6/1.5 = 1.067$
$\varphi_{C4/C6} = C_6/C_4 = 1.9/1.6 = 1.188$
$\varphi_{C6/C5} = C_5/C_6 = 2.0/1.9 = 1.053$
$\varphi_{C5/C8} = C_8/C_5 = 2.6/2.0 = 1.3$
$\varphi_{C8/C9} = C_9/C_8 = 3.1/2.6 = 1.192$
$\varphi_{C9/C7} = C_7/C_9 = 3.2/3.1 = 1.032$

$\varphi_{C2/C4} = C_4/C_2 = 1.1/1 = 1.1$
$\varphi_{C4/C1} = C_1/C_4 = 1.2/1.1 = 1.091$
$\varphi_{C1/C7} = C_7/C_1 = 1.4/1.2 = 1.167$
$\varphi_{C7/C8} = C_8/C_7 = 1.9/1.4 = 1.357$
$\varphi_{C8/C3} = C_3/C_8 = 2.2/1.9 = 1.158$
$\varphi_{C3/C9} = C_9/C_3 = 2.4/2.2 = 1.091$
$\varphi_{C9/C5} = C_5/C_9 = 2.7/2.4 = 1.125$
$\varphi_{C5/C6} = C_6/C_5 = 3.0/2.7 = 1.111$

The obtained results are entered into the Lingo program by which the weighted values of the criteria for each decision-maker are calculated.For DM$_1$ deviation fromfull consistency is 0.000, while criteria weights are as follow:

$W_1 = 0.215;$
$W_4 = 0.165;$
$W_2 = 0.119;$
$W_3 = 0.107;$

$W_5 = 0.9776700 \in -01 = 0.098;$
$W_6 = 0.8970874 \in -01 = 0.090;$
$W_9 = 0.79733436 \in -01 = 0.080;$
$W_7 = 0.6534600 \in -01 = 0.065;$
$W_8 = 0.6165723 \in -01 = 0.062;$

Deviation fromfull consistencyDM$_2$ je0.000, while criteria weights are as follow:

$W_1 = 0.191;$
$W_2 = 0.173;$
$W_3 = 0.127;$
$W_4 = 0.119;$
$W_6 = 0.100;$

$W_5 = 0.9546301\epsilon - 01 = 0.095;$
$W_8 = 0.7347345\epsilon - 01 = 0.073;$
$W_9 = 0.6170969\epsilon - 01 = 0.061;$
$W_7 = 0.5988204\epsilon - 01 = 0.060;$

Deviation fromfull consistency0.000, while criteria weights are as follow:

$W_2 = 0.180;$
$W_4 = 0.164;$
$W_1 = 0.150;$
$W_7 = 0.129;$

$W_8 = 0.9468341\epsilon - 01 = 0.095;$
$W_3 = 0.8178370\epsilon - 01 = 0.082;$
$W_9 = 0.7496707\epsilon - 01 = 0.075;$
$W_5 = 0.6665342\epsilon - 01 = 0.067;$
$W_6 = 0.6000868\epsilon - 01 = 0.060;$

After calculating the weights of the criteria for each decision-maker, the geometric mean of the obtained results, representing the final values of the weight coefficients, is calculated, which are:

$W_1 = 0.185$
$W_2 = 0.157$
$W_3 = 0.105$
$W_4 = 0.166$
$W_5 = 0.087$
$W_6 = 0.083$
$W_7 = 0.085$
$W_8 = 0.076$
$W_9 = 0.072$

Values that are shown represent criteria weights, which are later used for weighting normalized initial matrix.

After calculating the criteria weights, the supplier analysis using the MABAC method continued.Table 5 shows the geometric mean of supplier evaluation by decision makers, which is also the first step of the MABAC method:

Table5. Initial decision matrix

	C$_1$	C$_2$	C$_3$	C$_4$	C$_5$
A$_1$	5.94	5.19	6.65	6.32	6.26
A$_2$	6.32	3.83	5.19	4.82	6.65
A$_3$	4	6.32	5.31	4.64	4.64
A$_4$	3.3	6.65	4.76	4.93	4
	max	min	min	max	max

	C_6	C_7	C_8	C_9
A_1	6.32	5.59	7	7
A_2	6.32	2.41	3.98	6.65
A_3	3.91	3.56	4.58	4.64
A_4	3.63	3.11	4.93	3.63
	max	max	max	max

The second step of the MABAC method is to normalize the initial matrix. The results are shown in Table 6.

Table6. Normalized initial decision matrix

	C_1	C_2	C_3	C_4	C_5
A_1	0.876	0.516	0	1	0.852
A_2	1	1	0.772	0.11	1
A_3	0.232	0,118	0.708	0	0.242
A_4	0	0	1	0.174	0
w_j	0.185	0.157	0.105	0.166	0.087
	C_6	C_7	C_8	C_9	
A_1	1	1	1	1	
A_2	1	0	0	0.896	
A_3	0.105	0.360	0.199	0.299	
A_4	0	0.219	0.316	0	
w_j	0.083	0.085	0.076	0.072	

The normalized matrix values are weighted by the criteria weights obtained by applying the FUCOM method. Table 7 shows the obtained values.

Table7. Weighted normalized initial decision matrix

	C_1	C_2	C_3	C_4	C_5
A_1	0.347	0.238	0.105	0.332	0.161
A_2	0.370	0.314	0.186	0.184	0.174
A_3	0.228	0.176	0.179	0.166	0.108
A_4	0.185	0.157	0.210	0.195	0.087
	C_6	C_7	C_8	C_9	
A_1	0.166	0.170	0.152	0.144	
A_2	0.166	0.085	0.076	0.136	
A_3	0.092	0.116	0.091	0.094	
A_4	0.083	0.104	0.100	0.072	

The next step is determining the border approximation area matrix (G), and results as follow:

$$X = \begin{matrix} 0.271 \\ 0.213 \\ 0.165 \\ 0.211 \\ 0.127 \\ 0.120 \\ 0.115 \\ 0.101 \\ 0.107 \end{matrix}$$

After the obtained results, the fifth step of this method, the calculation of the elements of the distance matrix of the alternatives from the boundary approximation region, whose results are presented in Table 8, is applied.

Table8. Distance of alternatives from border approximation area

	C_1	C_2	C_3	C_4	C_5
A_1	0.08	0.02	-0.06	0.12	0.03
A_2	0.10	0.10	0.02	-0.03	0.05
A_3	-0.04	-0.04	0.01	-0.04	-0.02
A_4	-0.09	-0.06	0.05	-0.02	-0.04
	C_6	C_7	C_8	C_9	
A_1	0.05	0.06	0.05	0.04	
A_2	0.05	-0.03	-0.03	0.03	
A_3	-0.03	0.00	-0.01	-0.01	
A_4	-0.04	-0.01	0.00	-0.04	

The obtained values are summed by column and give the following results.

$$X = \begin{matrix} 0.385 \\ 0.261 \\ -0.182 \\ -0.238 \end{matrix}$$

In the ranking of alternatives, the highest value obtained using the MABAC method is the most suitable solution, while the lowest value obtained is the worst solution. Rank of alternatives as follow:

$$A_1 \rightarrow A_2 \rightarrow A_3 \rightarrow A_4$$

By analyzing all the data collected by the decision-makers and calculating the rank of alternatives using the MABAC method, Bramac represents the most suitable tile supplier for the company "Napredakpromet" d.o.o.

4. SENSITIVITY ANALYSIS

In order to validate obtained results sensitivity analysis has performed. Figure 1 shows the sensitivity analysis through the comparison of different MCDM approaches: EDAS [9], SAW [10], ARAS [23], WASPAS [24], TOPSIS [7]andCoCoSo[22].

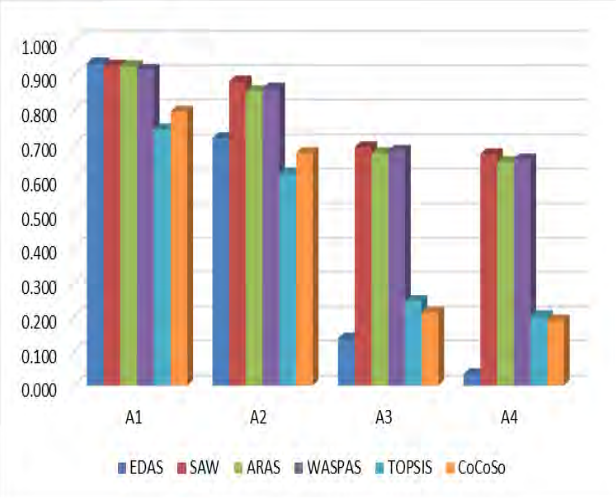

Figure 1. Sensitivity analysis

After performed sensitivity analysis and comparison with the other six MCDM methods, the ranks do not change, i.e ranks are completely correlated with each other. Figure 1 shows the values of alternatives obtained by applying different methods, where it can be observed that the best alternative according to all methods has an extremely high value.

5. CONCLUSION

In this paper has performed supplier selection, applying the MCDM method, for a company which deals with the storage and sale of construction materials. Selecting the right suppliers can be crucial for the company. In the supplier selection process, nine criteria are defined that have an impact when purchasing products. These criteria were analyzed using the FUCOM method to calculate the weighting coefficients, which are further needed to calculate the rank of alternatives using the MABAC method. Analyzing the assessments of suppliers obtained from decision-makers, a ranking of alternatives was obtained, according to which the first alternative represents the most suitable solution, while the fourth alternative represents the worst solution.

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Contact address:
Željko Stević
University of East Sarajevo, Faculty of Transport and Traffic Engineering
Doboj, Bosnia and Herzegovina

UNIVERSITY OF NIS FACULTY OF MECHANICAL ENGINEERING

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SMART, GREEN ASPECTS IN WAREHOUSES LOGISTICS

***Kristina JAKIMOVSKA*[1]**
***Anita VASILEVA*[1]**
***Slave JAKIMOVSKI*[1]**

[1)] University"Ss. Cyril and Methodius",
Faculty of Mechanical Engineering- Skopje;
North Macedonia

Abstract

One of the subsystems of logistics and keyword for the flow of goods and information is a warehouse. Investment in a new, smart technology can makethe strategy in a warehouse to be on a higher level. The main focus is on minimizing and reducing waste, gases, processes, and vibrations. The poor air quality, trucks and mechanisms in warehouses can easily be causing dangerous consequences to bio systems. Related to the idea of making the warehouse more ecological, the main goal of the paper is to show a new, "green" direction to logistics in a warehouse. The paper presents an overview of negative effects of pollution, processes, green solutions, and smart ideas for organization and optimization in a warehouse.

***Keywords**: logistics, warehouse, green logistics, smart technology.*

1 INTRODUCTION

Always, the limitations forced people to think about new solutions and alternative ideas. Travel back in the past, not all the commodities were produced or were available where people wanted to be. For that reason, people started to develop the efficiency of the production of local goods and started to import goods that were not locally produced. This is the beginner steps of the logistics. As logistics systems were developed, they play a significant role in reassuring a high level of foreign trade. Now, directly or indirectly, the logistics processes are involved almost in every sphere of human activity. All areas of logistics have a significant impact on a price, efficiency and effectiveness. Basically, the value in logistics is in terms of time and place.Good logistics management views each opportunity of adding value. [1] [3] [4] To achieve the customer‶s requirements and needs a warehouse, like subsystem of logistics, must be properly coordinated and controlled. Good strategy of the warehouse is focused to optimize every unnecessary movement, space and extra costs. In this age, in a world where technology has sprung up in every sequence, the warehouse is not out of the grid. The foremost element of modern supply chains as a competitive strategy to improve organizational performance is the warehouse. The role of the warehouse has been changing over the recent years. With the dynamic customer demands, it has been difficult to meet the requirements with the traditional warehouse.

2 EFFECTS OF LOGISTICS 4.0 IN THE WAREHOUSING PROCESSES

A fourth industrial revolution in the context of warehousing, smart logistics and smart warehouse concepts has been evolving all over the world with a goal to eliminate the disadvantages of the conventional warehouse systems. (Fig. 1 Market size and growth of smart warehouse in China). New warehouses are becoming more and more automated, with the main idea being to move products from one place to another in the shortest time. To accomplish all this system of automated mechanisms and retrieval machines, programmable controllers and software manipulate them. The point is how the technology in the warehouse has evolved, but more interesting is what the next step is? [5][6]

More than ever, data and information are easily available. However, that data and information are useless unless they are connected and used correctly. Available technologies now use hardware such as sensors, scanners, and GPS trackers to give precisely a relation between inventory and associates in the warehouse at any time. Identification, flexibility and even the prediction, to customer needs, is an advancement that nowadays warehouse cannot afford to be without. Internet availability on handheld devices can connect the data instantaneously and quickly processing. This technology makes a revolution in supply chain management because provides visibility and precision. Users can get a clear picture with tracking through GPS location devices and to make precisely and optimal plans for warehousing. [5][7]

***Fig. 1** Market size and growth rate of smart warehouse in China (Source: GGII)*

Providing users with access to data and information, combined with smart technology, prevents supply chain interruptions. Sensor technology has ensured that can map every warehouse, to make analyses of inventories and reveal the placement and location of every product. [9]
While the business may not be able to support all of the changes immediately, smart technology is the perfect opportunity for flexible changes in warehousing. The use of a data leads to many benefits. The analytics are performed on the data sets to calculate resource demands and to make better planning. New scenarios are being tested with simulation practices. Autonomous systems are improved due to data obtained from sensors, which map their direct environment. (Jeske & Grüner 2013 p.6; Witkowski, K.2017a, p.765; Wang et al.2016/6 p.99-100)

3 EFFECTS OF WAREHOUSING FOR THE ENVOERMENT

Warehousing industry is involved in air quality. As the industry developed, more workers and citizen are witnesses to warehousing pollutants.
The main indoor pollutants in a warehouse are docks and forklifts. The product of these pollutants is carbon monoxide, hydrocarbons, nitrogen oxides, also, sometimes toxic mold is an issue in warehouses that are located in areas with high humidity and in poorly ventilated areas of a facility.
Besides the logistics that create carbon dioxide pollution, warehouses consume a serious percent of energy. This leads to an expansion in carbon dioxide emissions from the energy sector, directly caused by the expansion of warehousing. Research indicates that one of the worldwide, top contributors to lung cancer is from diesel trucks serving in the warehousing industry. [10]
The World Logistics Center estimates that one in 10,000 residents that live nearly to the warehouses could develop cancer, in addition to one in 50,000 residents who live in the surrounding area. [8]
In parts of North America and Europe, air pollution can be high, but it has improved slightly over the past decade with new environmental regulations and progress in technology. Meantime, China and India have been frequently cited as areas where air pollution is at its worst.
Improving any segment of the warehouse's work involves a lot of detail. Even if technology can affect the progress of the storage methods', it cannot change the basic functions. New data processing systems cannot reform inadequate information management procedures, eg. The crane cannot clean the dirty warehouse. [6][8]
According to information from the “Fire Foundation”, warehouses consume 36% of the total US energy consumption, 65% electricity; 30% raw material and 12% drinking water (Stojanovic, 2012). Other research shows that 65-90% of the energy stored in warehouses is spent on activities for heating, ventilation, cooling, lighting, and equipment. [6][7]
Air pollutants can be greatly expanded from their original source. Not only air pollutants are harmful for the environment, there are many other elements. [14]
The negative effects of noise are problems in communication, decreased concentration, ie, reduce overall productivity, mental problems and cardiovascular problems.
The last years, the European Union has increasingly introduced rigorous measures to limit noise in road transport and in workplaces.

4. VALUE OF GREEN STRATEGY IN THE WAREHOUSES LOGISTICS

Green Logistics is a logistics which direction is to preserve the environment. As we know, global warming, pollution, natural resource constraints, transportation, waste problems, we are urged to pay serious attention to reducing a big part of it. There are two ways that we can act:

- Rational use of waste materials and
- Rationalization of logistics processes.

Green logistics contains several contradictions. The purpose of logistics is to reduce costs, time savings, increase reliability and flexibility, but with using green logistics on the first view there is no cost cutting. [16][17]
Time is usually the most important result of logistics operations, and by reducing the time, productivity is increasing. [19]
In this paragraph, it will be dwell the opportunity of new technologies that offer environmental improvements. In recent years, researchers have focused on how to reduce sulfur in exhaust gases, and the use of low-sulfur ultra-fuels are currently a normal occurrence. In the fig. 2, there is one statistic about success of green initiatives for shippers.

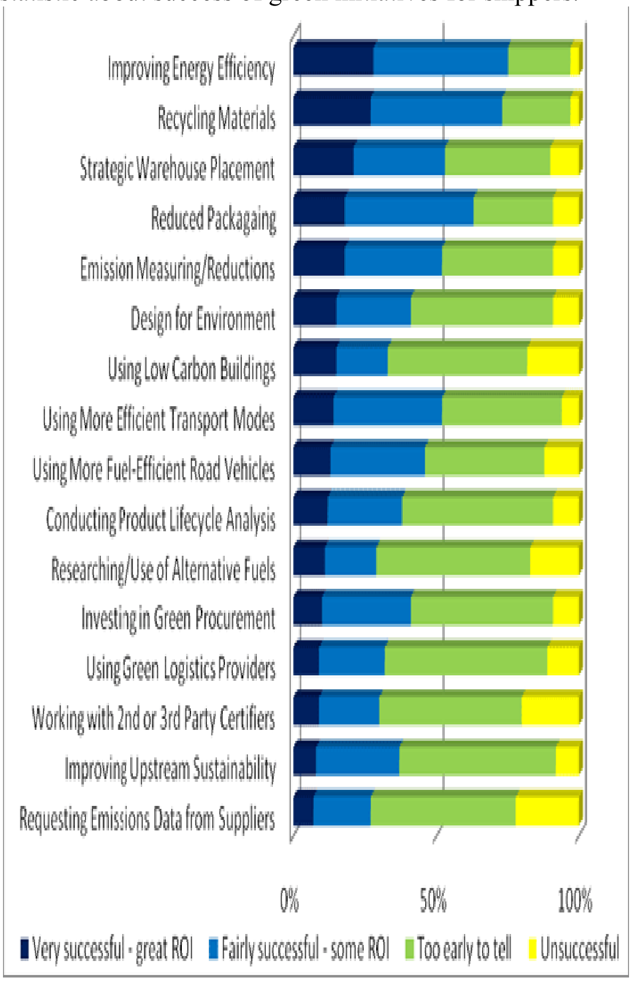

Fig. 2 *Success of green initiatives for shippers (Source: Enviroment + Energy Leader ROI Driving Supply Chain Sustainability, June 17, 2010, by Paul Nastu)*

Some studies calculated out that reducing inside warehouse temperature lead to an appreciable reduction in energy consumption; for example, 1-Celsius degree is decreased, 10% energy will be saved. Therefore, warehouse managers need to decide the optimal temperature in each area in the warehouse and on this way to criticize to cheapen monthly energy. By 2025, some solar cells could even be included in the pavement of the parking. Already, there have been countless examples of green projects around the world; some of them normally are connected with green warehousing. It is likely that most of the initiatives usually focus on current resources, but refrain from future proposals to further possibilities. Enterprises must look to the future and plan for the forthcoming outlook of opportunities. [6][9]

More and more data are going to be used in warehousing and transportation. Every movement in a warehouse is recorded but not totally utilized yet. Artificial intelligence advanced planning capabilities and algorithms are going to be able to isolate the effect of events to better model the load and the capacity. This applies to both planned events and disruptions (disruption, planned even, disruption- snow, strike etc.)Every sequence of giving rise to green warehousing is a step towards, but the most promising methods of future green warehouse: energy self-production and sustainable building design. [8][9]

4.1. Green-smart energy generation

A modern, futuristic warehouse can self-produce partial or nearly full energy needed by using renewable energy sources. This can be a perfect approach to cut off emissions and greenhouse gas as well as save energy costs. Several most modern, smart and clean sources of energy are solar, biomass, and the wind. (Richards & Riding 2015, 367.) [10] As a result, of economies industrialization, demand for vehicles is likely to increase. The effect of this can go in two ways: either those cars can be reliant on fossil fuel combustion, or they can be relied on renewable energy. Air pollution can dramatically reduce from vehicles by using hybrid and electrical vehicles. [10]

In the countries with the highest populations (India, China and Nigeria), in the coming decades, the number of cars is likely to grow considerably, which will be particularly marked in Africa, and substantial too in South Asia.If those countries were to have the same motorization rate for each person as the USA currently, the number of vehicles would increase by nearly 40 times for India and Nigeria, and 8 times for China. This also does not include the growth in population over the coming decades. The reason to invest in green could not be stronger. [8][9]

Lighting, household cooking and heating are a major cause of household, or indoor, air pollution. Nearly 3 billion people worldwide are put at risk of ill health and early death by indoor air pollution. Indoor pollutants include particulate matter (PM10 and PM2.5), dust mites and bacteria, as well as chemicals such as formaldehyde and benzene from paints, products for personal care and building materials.[7]

The difference between outdoor and indoor air pollution is less useful for practical purposes, but it is useful for analytical purposes. Throughout the day, we move between indoor and outdoor environments and it is hard to classify the many microenvironments between indoor and outdoor.The investment of energy self- production is a good choice only for huge warehousing and if governments provide necessary incentives as well, as enforce compulsory regulations. It seems that government' politics and power play a vital role in green energy generation. (Richards & Riding 2015, 367.) [8][10]

Nonetheless, due to the extensive capital investment, self-production of energy in a warehouse, for now, is just an environmentally-friendly method but it is not a cost-efficient justify. Consequently, choosing an affordable way to self-produce energy is a hard task. Solar panels are a very expensive investment and usually requires about 15-20 years of payback. On the other hands, electricity, wind turbines have much fewer prices, and their returns on investment are generally within five years. However, a decision for investment requires a large analysis of payback invest, before managements make a green decision. (Baker & Marchant 2015, 213.) [8] [7]

See figure 4 for yearly new investments in solar power (Source: UNEP, Bloomberg New Energy Finance (2016)).

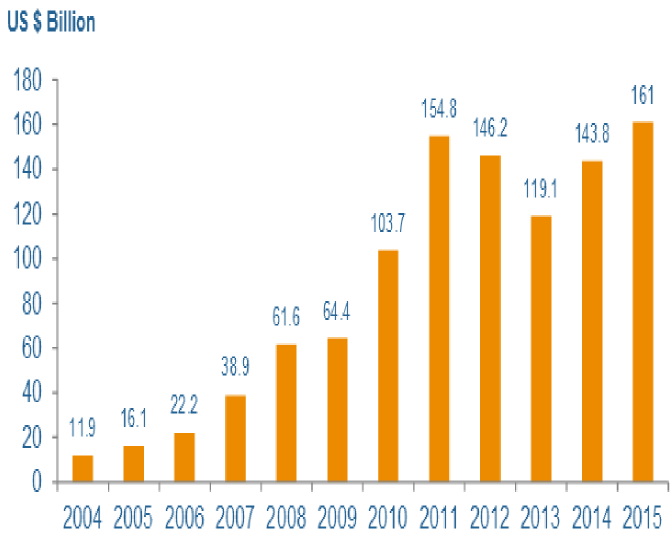

Fig. 4 *Yearly new investments in solar power (Source: UNEP, Bloomberg New Energy Finance (2016))*

5. CONCLUSION

The research outcome can provide insightful information and directions for green logistics. These data can help to make a global picture and to keep track of the situation of logistics and energy efficiency and as well as to enable better decision- making a process in the future. Last but not least, although the main direction is to implement energy self-production, this paper suggested using different efficient types. The way of green solutions and ideas without limit. Green logistics can be on the scene, even if there is new, smart technology. Every idea is an additional approach; there are always needs for continuous research on green energy sources. In the future: buildings, urban areas, cities, regions and countries may become more or less energy self-sufficient. The future smart technology will be focused, efficient, cost-effective and integrated.Therefore, when planning projects for the implementation of green and smart technologies, first, it is necessary to take informed of economically acceptable energy efficiency measures and then the application of renewable energy sources. However, the application of renewable energy sources is becoming financially more attractive in the past years.

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Contact address:
Kristina Jakimovska
University "Ss.Cyril and Methodius"
Faculty of Mechanical Engineering - Skopje
Karpos bb P.O.Box 464, 1000 Skopje, North Macedonia
E-mail: kristina.jakimovska@mf.edu.mk

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AN APPLICATION OF A GENETIC ALGORITHM FOR THE FLEXIBLE JOB-SHOP SCHEDULING PROBLEM

Aleksandar STANKOVIĆ [1]
Goran PETROVIĆ [1]
Ţarko ĆOJBAŠIĆ [1]
Miloš MADIĆ [1]
Natalija TOMIĆ [1]

[1)] *Faculty of Mechanical Engineering, University of Niš*

Abstract

This paper deals with scheduling jobs in a production system based on application of a genetic algorithm for the flexible scheduling problem. The problem of flexible planning and scheduling (FJS) is known in the research literature as one of the most difficult optimization problems and represents one model with different optimization goals. This kind of real-time scheduling and scheduling problem is a big challenge and is applicable to all industrial environments depending on the needs and purpose of research. This problem occurs when, at certain moments of planning, products are machined, where instead of one machine, there are several machine centres with machines of the same type that can perform the same type of machining on machines. The FJS problem can be classified according to the degree of its flexibility in scheduling operations on machines, which are the main research motive and goal of this paper, as well as the applicability of the genetic algorithm in such a case study.

***Keywords**: flexible job-shop, scheduling problem, planning, metaheuristics , genetic algorithm*

1 INTRODUCTION

One of the most important issues in manufacturing is scheduling operations and managing production processes. A key reason for scheduling and planning production processes is to accelerate production productivity. Planning and scheduling production operations can be very easy, but it can also be one of the most difficult scheduling problems that could be seen in the research literature, depending on the type of problems and planning conditions. It should be noted that the Job Shop problem is one of the most difficult NP problems in combinatorial optimization. Extension of the above JS problem to a problem in which there are more than one available machines for each phase of processing operations, is known as FJPS.
The main difference between the FJS and the JS is that with this type of problem, there is flexibility in scheduling operations on multiple machines, that is, the scheduling of operations on machines is not predetermined. In this approach to solving the problem of flexibility, it is realized that each machine has the ability to perform more than one type of operation hence the name FJS. In recent years, research on scheduling and planning has largely used meta-heuristics as an advantage over heuristics and classic dispatch methods. A genetic algorithm for solving FJS problems is proposed in this paper. In the second part of the paper an overview of the research literature is presented as well as the methodology used to optimize the scheduling production and process.

2 LITERATURE REVIEW

As can be seen in the previous part of the paper, most of the scheduling problems belong to the group of NP-difficult problems, so the ways of solving this type of problem are divided into several methods, which is presented in Figure 1:

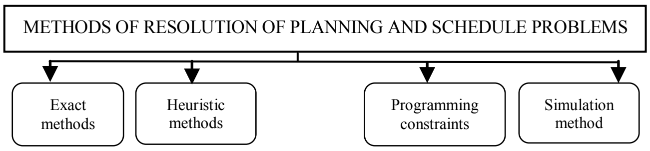

Figure 1. Methods for solving scheduling problems

Exact methods: The basic feature of these methods is the precise definition of mathematical means and the finding of optimal solutions depending on the size of the data examined. To this group, defining models for considering scheduling problems and scheduling the basic techniques used are techniques of nonlinear, linear, dynamic, integer and disjoint programming. There are many exact algorithms in the research literature that are used to solve such research problems, such as Branch and baund methods, and they can be defined through various techniques for determining the lower and upper bounds, through appropriate branching strategies, as can be seen in previous research papers on this by a method such as [1], [2]. They defined the problem [3], [4] with the Lagrangian relaxation method, where they proved that the planning problem can be successfully solved with this method. Also [5], [6], [7] solved the scheduling and planning problem with an integrated planning method. [8] worked to improve the algorithm they had already [9] developed to improve time complexity.
Ostergard proposed a branching and bounding algorithm that defines and analyzes nodes by staining, which at that point represented a new strategy for marking nodes and thus rejecting individual nodes. He used an improved reduction technique to write search and thus compared his algorithm with other algorithms and proved that his algorithm was more optimal [10].
Heuristic Methods: One of the first significant steps in the development of evolutionary algorithms was developed by John Holland and his associates at the University of Michigan in the 1960s and 1970s. Such methods when

searching for a solution do not guarantee to find the optimal solution, but very effectively find a good enough solution in some real-time. Heuristics are divided into heuristics that give only one solution within the search and heuristics that give results during the search through a series of iterative solutions.

Papers [11], [12], [13], [14], [15]; [16] are just some of the references that deal with the method described in the example of resource planning and scheduling.

Programming constraints: There are number of different software applications used in this category of problem-solving, with the possibility of programming constraints in scheduling problem-solving. The limitation programming technique can be applied to the scheduling problem in production, such as JS, FJS, and many other similar examples. Examples of solving JS scheduling and scheduling problems can be seen in [17], [18]. Some examples of solving the FJS Problem based on the Genetic Algorithm and other constraint programming algorithms can be seen in the papers [19], [20].

Simulation Methods: Simulation modelling has a great ability to present complex systems in a multitude of details, which is its main advantage over other methods. Simulation-based scheduling and planning are quoted for a multitude of operations and system controls and as a final output is a detailed work plan. Simulation-based scheduling approaches are derived from a group of dispatch approaches based on defined rules during scheduling. To automatically search for the speed of the optimal solution, the scheduling problem can be solved by using SBO simulation, an approach in which the simulation model is integrated with metaheuristic search methods such as GA and TS. Also some of the methods that can be used to solve scheduling and scheduling problems based on simulation methods are: Kanban [21] Work Load Control (WLC), as well as ConWIP (Constant Work-in-Process) variants , POLCA (Paired Cell Overlapping Loop of Cards with Authorization) [22], [23]. In many cases, when planning and selecting a job, the rules of the job priority are used, depending on the delivery time of a particular type of product. [24] state that this is one of the most important factors during the planning process in small and medium-sized enterprises. Such methods are of great use in the form of simulations in the form of solving JS problems [25].

In this paper on the basis of previous alternatives, application of GA to a representative case study is presented solving a specific example of the FJS Problem by applying the artificial intelligence of the GA algorithm.

3 METHODOLOGY

As a methodology for solving planning and scheduling problems in an industrial environment, the example of manufacturing process planning in this case study of machines and operations used the case of constraint programming within meta-heuristics, which can be seen in the previous section of the literature review section. The term meta-heuristics was first proposed by Fred Glover back in 1986 to define meta-heuristics many years later as a set of algorithmic concepts used to define heuristic methods applicable to a broad set of problems [26].

Meta-heuristics are conceptualized to solve complex optimization problems where other optimization methods fail to effectively and economically solve the optimization problem [27], [28]. Today, these methods are recognized as one of the most practical approaches to solving many complex problems, and this is especially true of solving many real-world problems that are combinatorial in nature, such as the planning and scheduling problem in the industry itself. Generally, meta-heuristics can be said to be higher levels of heuristics.

3.1 Genetic algorithm

Genetic Algorithm (GA) is an optimization technique used to solve nonlinear or non-differential optimization. The GA algorithm was developed by Holland in the 1970s. It is characterized by several stages in solving a defined problem in this case of planning and scheduling. This algorithm mimics the natural selection process, changes in the genetic structure are possible by mutation of genetic material whose essence is to widen the search area and to overcome local extremes. Cross-referencing in GA is a combination of several units to get a new unit selected, this type is compared to a natural process like parents and their offspring. New individuals inherit their parents' genes.

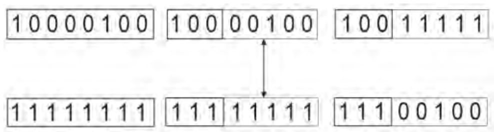

Figure 2. View of the crossing process

There are two types of crossover methods used to exchange genetic material, namely*: Subsequence Exchange Crossover*, which is a substring crossing on individual machines and a *Job-Based Order Crossover* crossover based on the product order. When it comes to solving planning and scheduling problems, the most common examples of solutions are based on a genetic algorithm when we talk about JS and FJS. One of the most common solutions is based on a coded job scheduling matrix used for scheduling problems on more than one machine, an example of such a matrix can be seen in Figure 3.

M1: O_{11}; O_{13}; O_{12} ⟶ M1: J_1; J_3; J_2
M2: O_{22}; O_{23}; O_{21} ⟶ M2: J_2; J_3; J_1
M3: O_{31}; O_{32}; O_{33} ⟶ M3: J_1; J_2; J_3

Figure 3. Job scheduling matrix

The mutation implies similar changes in the genes of individuals in the population. Mutation achieves uncontrolled alteration of genetic material. Changing the genetic structure results in completely new solutions. The basic goal is to get an individual that cannot be obtained in other stages.

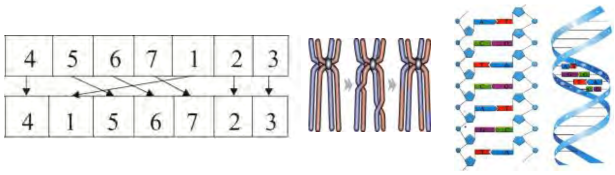

Figure 4. Mutation in the schedule of operations

This random value initiates a search across the allowed domain, and the solutions cannot converge prematurely. The mutation rate should be small from about 0.001% to 0.01%, in order to avoid a random, stochastic and uncontrolled procedure.

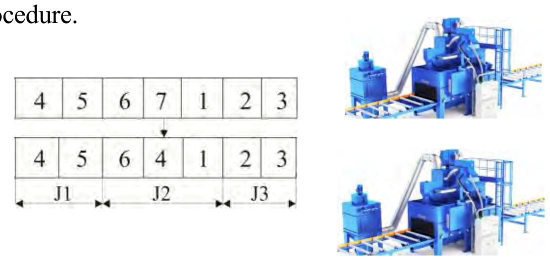

Figure 5. Mutation in schedule machine

4 CASE STUDY

This case study covers the planning and scheduling of production cycles, related to FJS problem-solving. The basic structure of the problem being addressed refers to a set of jobs that need to be done on the machines, and each job is broken down into a list of activities that are processed in the order. The essence of the problem and the defined activities is to keep the total completion time as small as possible according to the scheduled operations with the defined time of each operation individually. The set of operations performed to make one job complete and therefore a finished product. The mathematical model of the FSJ problem can be represented as follows [29].

It is necessary to arrange *n* products $J = \{J_1, J_2, \ldots, J_n\}$, with each job J_j $(j = 1,2,\ldots n)$ having a predetermined sequence of n_j operations ($O_{1,j}, O_{2,j}, \ldots .O_{nj,j}$) they are to be realized in the order given in *m* machines $M = \{M_1, M_2, \ldots, M_m\}$. For a problem that is completely flexible, each machine can only perform one operation at a time, and the processing times of each operation depend on the available machines and are represented by $p_{,i,j,k}$ (processing time of the operation $O_{i,j}$ on the machine M_k). The goal of the observed problem is to allocate each operation to the appropriate machine and then to determine the layout of all the machines assigned to the operations in order to minimize the objective function, in this case, minimize the production process based on the Genetic Algorithm. An example of the problem examined is presented in Table 1.

Table 1 Input matrix of partial FSJ problem

Jobs	Operations	M_1	M_2	M_3	M_4	M_5	M_6
J_1	O_{11}	7	-	1	5	-	-
	O_{21}	3	-	-	5	-	8
	O_{31}	-	6	-	7	-	10
	O_{41}	7	-	5	7	-	-
	O_{51}	-	5	-	-	6	3
	O_{61}	7	-	-	-	6	3
J_2	O_{12}	-	8	-	8	-	9
	O_{22}	5	-	5	-	-	4
	O_{32}	10	-	11	-	10	-
	O_{42}	8	-	7	-	-	10
	O_{52}	10	-	-	10	-	12
	O_{62}	-	7	15	4	-	-
J_3	O_{13}	8	-	5	-	7	-
	O_{23}	-	4	-	4	6	-
	O_{33}	-	-	-	-	-	8
	O_{43}	9	-	8	-	7	-
	O_{53}	-	3	-	5	-	3
	O_{63}	-	5	6	-	7	-
J_4	O_{14}	-	5	-	6	-	9
	O_{24}	5	-	4	-	8	-
	O_{34}	9	-	5	-	-	10
	O_{44}	5	11	-	3	-	-
	O_{54}	15	-	9	-	8	-
	O_{64}	-	10	-	11	-	9
J_5	O_{15}	9	-	9	-	9	-
	O_{25}	-	3	6	-	8	-
	O_{35}	-	6	7	-	5	-
	O_{45}	-	6	-	5	-	4
	O_{55}	3	-	4	-	4	-
	O_{65}	-	8	-	6	-	9
J_6	O_{16}	-	3	-	5	-	4
	O_{26}	8	-	-	3	6	-
	O_{36}	7	-	8	-	-	9
	O_{46}	10	-	8	9	-	-
	O_{56}	-	9	-	10	4	-
	O_{66}	7	-	6	-	8	-

It should be noted that not all machines need to be able to perform all the operations as can be seen in the attached Table 1. This troubleshooting approach is called partial troubleshooting or partial flexibility where some operations can only be performed on specific machines. Such examples are much more common in real-world cases during optimization of production processes. Table 1 of the problem described can show 6 jobs and 6 machines, job 1 has 6 operations, the first operation can only be processed by one machine and that machine is M_3 with a processing time of 1. We can see the graphical results of the first investigated case of partial research flexibility in Figure 6 in the Gantt chart.

One of the most common cases when planning production is Gantt charts and as they are called in the research literature, Gantt charts. The charts were introduced by the American scientist Henry Gantt.

The Gantt chart is a diagram in a coordinate system in which the horizontal axis is time, and the vertical axis lists the planning tasks on which to determine: start, total duration and end of the cycle, which is a major problem in determining the schedule and schedule in this case the machine and operation [30].

Another examined case of planning and scheduling is called total *FJS* where each operation can be deployed on any of the *m* machines available because all machines are capable of performing each operation at a given time for a defined processing time of each operation. An example of the problem examined is presented in Table 2.

Table 2 Input matrix of total FSJ problem

Jobs	Operations	M_1	M_2	M_3	M_4	M_5	M_6
J_1	O_{11}	7	11	9	7	8	9
	O_{21}	3	6	12	10	5	7
	O_{31}	5	6	6	11	7	10
	O_{41}	5	5	7	7	8	7
	O_{51}	9	5	10	9	6	3
	O_{61}	10	3	11	8	6	7
J_2	O_{12}	7	8	7	5	7	7
	O_{22}	4	7	5	10	9	8
	O_{32}	5	7	9	10	10	9
	O_{42}	3	5	11	10	9	10
	O_{52}	10	7	9	9	6	6

	O_{62}	3	9	5	4	11	10
J_3	O_{13}	5	6	5	7	8	9
	O_{23}	2	5	9	4	8	9
	O_{33}	8	5	9	10	10	8
	O_{43}	9	5	9	10	11	8
	O_{53}	7		7	10	7	9
	O_{63}	7	9	9	10	7	11
J_4	O_{14}	7	5	7	8	9	10
	O_{24}	5	5	7	9	9	9
	O_{34}	5	9	5	10	6	10
	O_{44}	6	7	8	3	9	3
	O_{54}	2	5	9	9	8	10
	O_{64}	7	9	9	10	11	9
J_5	O_{15}	9	5	9	8	10	11
	O_{25}	6	5	5	8	10	6
	O_{35}	9	5	9	10	5	9
	O_{45}	5	9	10	11	12	4
	O_{55}	3	5	5	6	9	11
	O_{65}	9	8	9	8	10	7
J_6	O_{16}	2	3	9	8	10	7
	O_{26}	2	5	9	3	9	7
	O_{36}	2	5	9	9	10	9
	O_{46}	10	9	10	9	9	10
	O_{56}	9	5	10	6	4	9
	O_{66}	10	5	9	4	9	8

Table 2 shows the input parameters of the test problem where we have 6 jobs (products) where each of these 6 jobs has 6 operations, each of which defined operations with machine processing time in minutes can be performed on each machine.

As we can see in the previous part of the paper, we call this case complete flexibility. Graphical results of the survey can be seen in Figure 7.

As for the implementation of the GA algorithm, the experimental results were tested in python and the numerical values were derived on standard MS Winows based PC platform.

5 RESEARCH RESULTS AND DISCUSSION

After introductory discussions and clarification of the FJS problem, as well as a review of the research literature on the topic of planning, a specific set-up of the problems and results of the planning was made. It is important to note that the tested test data is randomly given. As can be seen in the previous part of the paper, two cases of planning and scheduling were tested, which was at the same time the aim of this problem. Table 1 shows that not every machine can perform every operation during the planning and scheduling of operations. Partial flexibility is one of the most common causes that can be encountered in manufacturing, it is often the case that not every machine can perform every operation to get the job (product) done. The results of the input data in Table 1 are graphically presented in the chart in Figure 6 for the first case of partial flexibility. In Figure 6 we can see the layout of operations on individual machines depending on the initial constraints. I define each job in a different colour to differentiate jobs (products). On the horizontal axis, time is presented with the criterion function value C_{max} = 218 units in minutes. Regarding testing, it was noted that the search was performed by Genetic algorithm with MaxIter = 500. GA based search in a python programming language, that is, total panning and scheduling time is 41.63 seconds for the first case tested. On the vertical axis, we can see all 6 machines that are linearly aligned. With regard to the second case examined, it is presented in Table 2 and is clearly different from the first case examined. In Table 2, based on the input data presented, it is possible to see complete flexibility where each machine can perform each operation with defined time.

Also, in this case, we have $J = 6$ jobs (products) and each of the jobs has $O_{ij} = 6$ operations that can be performed on each machine depending on the schedule of operations with a defined processing time of each operation individually. On the horizontal axis, we can see the total time represented by the value of the criterion function C_{max} = 652 units in minutes.

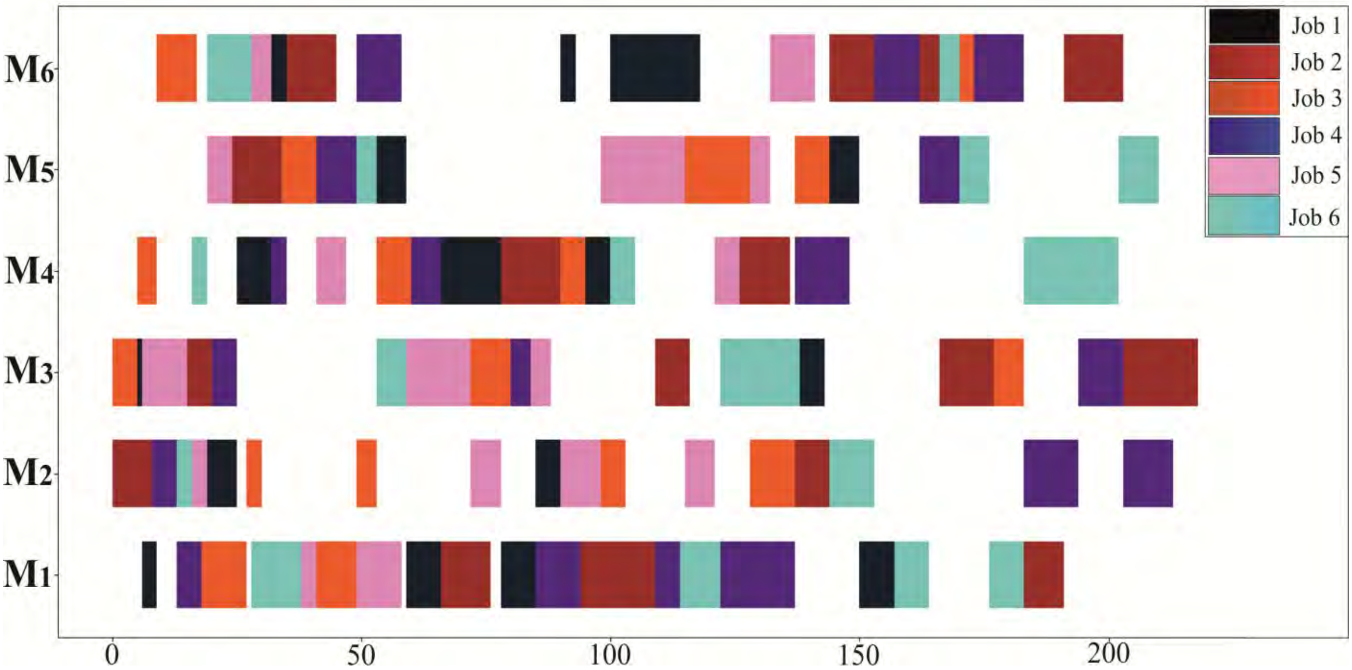

Figure 6. Graphical representation of the input data of Table 1

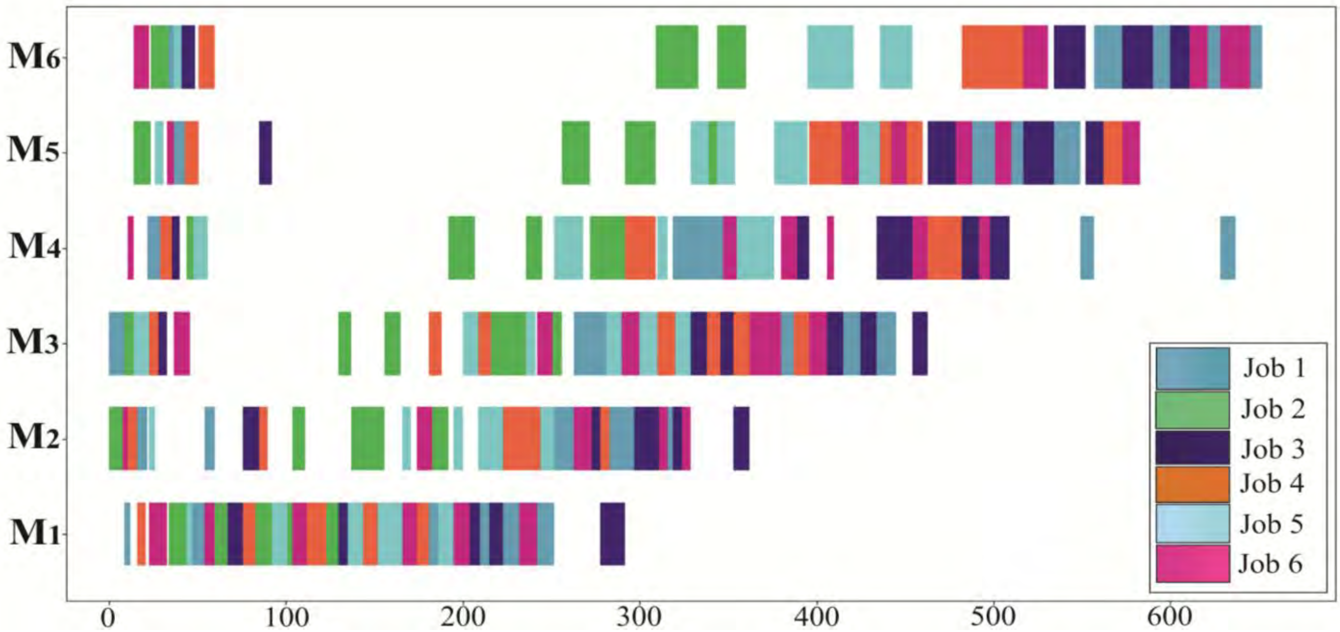

Figure 7. Graphical representation of the input data of Table 2

The value of the criterion function representing the total time of completion of all operations and the completion of the planning process is represented by the C_{max} mark, which could be seen in the previous part of the paper and is presented in minutes. The Gantt chart presents a detailed schedule of operations that will be performed on machines. The machines are represented linearly on the vertical axis. The total simulation time based on the GA algorithm in a python programming language is 90.89 in seconds.

The objective of the investigated problem of planning and scheduling operations was successfully achieved, as can be seen from the attached results, thus confirming the success of solving the FJS problem by the GA algorithm.

With regard to proposals for further research, the FJS problem can be further expanded by observing the available workers involved in the realization of production activities. In this problem, workers and machines are limited, and the problem is called double-restricted flexible work.

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Contact address:
Aleksandar Stanković
University of Niš, Serbia
Faculty of Mechanical engineering
18000 Niš
A. Medvedeva 14
E-mail: aleksandar.stankovic@masfak.ni.ac.rs

UNIVERSITY OF NIS FACULTY OF MECHANICAL ENGINEERING
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THE LOCATION SELECTION PROCESS FOR BATTERY CHARGING STATIONS FOR TWO-WHEEL ELECTRIC VEHICLES REGARDING THE IMPORTANCE OF URBAN MOBILITY IN THE CITY OF NIŠ

Jelena MIHAJLOVIĆ[1]
Goran PETROVIĆ[1]
Nikola PETROVIĆ[1]
Predrag MILIĆ[1]
Dušan ĆIRIĆ[1]

[1)] *University of Niš, Faculty of Mechanical Engineering*

Abstract

The worldwide phenomenon such as global warming, supported by air pollution caused by traffic congestion with fossil fuel combustion has become a major problem in every city. This paper shows the MCDM (Multi-Criteria Decision-Making) methodology approach in the location selection process. Criteria weights has been determined by CRITIC (Criteria Importance Through Intercriteria Correlation). TOPSIS (Technique for the Order Preference by Similarity to Ideal Solution) has been used for evaluation and selection of the proposed battery charging stations for two-wheel vehicles, regarding the improvement of urban mobility in the city of Niš. The location selection process for battery charging stations is highly important from the perspective of harmonious and sustainable development.

Key words*: battery charging stations, electric vehicles, location selection, MCDM, CRITIC, TOPSIS*

1 INTRODUCTION

The main cause for the emission of the greenhouse gas, carbon dioxide (CO_2), is the consumption of fossil fuels. UN Urbanization Statistics report from 2018 says that 25% of the CO_2 is estimated to be caused by urban transport of which 58% can be attributed to passenger transport [1]. With the rapid development of urbanization and an increase in the automobile industry, air pollution and energy problem become intense problems nowadays [2, 3].

Medium-sized and large cities [4] with rapid population growth (following the same UN Urbanization Statistics report from 2018 – 55% of the world's population lives in urban areas, and this proportion is expected to increase up to 68% by 2050 [1]) and poor urban mobility development (traffic congestion, fatalities and injuries, environmental pollution and energy consumption), rely on unsustainable public transport and streets crowded with automobiles. Traffic congestion is inevitable and air pollution is on its maximal level for the whole day. This way, human life is directly affected.

One of the approaches that have been developed over the years to reduce those negative effects is the use of electric vehicles (EVs) [2]. EVs, as an alternative way of transport with clean energy, are more efficient than equivalent conventional internal combustion engines (ICE) and generate lower emission of greenhouse gases by converting energy demand from fossil fuel to electricity [2, 3, 5].

EVs are driven by a motor, whose power is supplied by a rechargeable battery or other portable energy storage device [3]. There are four main types of EVs and the focus of this paper will be the location selection process for battery charging stations for the fourth type of EVs, which are battery electric vehicles (BEVs) [3, 6].

Problems that occur by using BEVs are, mainly their high costs, limited driving ranges and long charging time [6]. To overcome those problems and to get in a situation of a full acceptance of this concept, the existence of an appropriate network of battery charging stations (EVBCS – Electric Vehicle Battery Charging Stations) [7, 8]. Efficient, reliable, cost-effective and correctly positioned EVBCS network is crucial for this concept's success. Improper placement and sizing of EVBCSs may cause adverse effects and furthermore damage urban mobility in the city.

The EVBCS location selection problem includes many conflicting criteria and one of the approaches to select the most suitable battery charging locations is a multi-criteria decision-making (MCDM) methodology.

The MCDM methodology is widely used in the field of location selection and urban mobility improvement, as well as on the field such as green logistics (impact on the environment and social area [9]).

The selection of the suitable MCDM method for a given decision-making problem, in the present study battery charging location selection, is the key which ultimately determines the quality of the whole decision-making process. When applied for solving location selection problems, the MCMD methods can help decision-makers with objective and systematic evaluation of alternatives concerning multiple conflicting criteria with different levels of importance. For the present research – a hybrid MCDM approach, CRITIC (Criteria Importance Through Intercriteria Correlation) + TOPSIS (Technique for the Order Preference by Similarity to Ideal Solution) has been applied for the determination of criteria weight (CRITIC) and evaluation and selection of the proposed alternative solutions (TOPSIS).

2 LITERATURE REVIEW

Increase of the EVs presence and their constant development has initiated an increase in the literature which is focusing on the site selection of charging stations, as well as on seeking the optimal scales and reducing the cost of charging infrastructure [3, 6, 10].

For this research, only the literature regarding the location selection problem for battery charging stations will be briefly analyzed.

Electric power is different from fossil fuels derivates, such as gasoline, as it cannot be stored in large amounts and must be kept in real-time balance between power generation and consumption, which makes the problem of optimally programming EVBCSs much more complicated. In addition, this problem involves multiple elements and a variety of conditions, which increase the complexity even more [3, 11].

Many researches are committed to optimally planning or operating EVBCSs, which has their basic solutions in optimal positions of the charging sites.

EVBCSs location selection is a multiple-criteria evaluation problem.

For that reason, some studies that were performed in the last years on the multiple-criteria location selection were analyzed to determine the criteria and appropriate methods that were used for the selection of battery charging stations locations.

Some researchers have applied the TOPSIS method for the EVCS site selection from a sustainability perspective, which consists of environmental, economic and social criteria [12]. Also, the PROMETHEE MCDM method has been successfully used in the study of site selection problems for electric vehicle charging stations [13]. One of the analyzed studies has combined three MCDM methods: DEMATEL, AHP, and TOPSIS method, which were applied to evaluate alternative locations for EVs charging stations [2]. One of the authors involved the fuzzy Pythagorean approach and combined it with the VIKOR MCDM method to solve the complex multi-criteria site selection problem of charging stations [6].

3 MCDM METHODOLOGY

Multi-criteria analysis methods have been developed as mathematical tools to support decision-makers involved in the decision-making process [14, 15]. Those methods are gaining importance as potential tools for analyzing and solving complex real-time problems due to their inherent ability to evaluate different alternatives with respect to various criteria for possible selection of the best alternative [16].

The choice of the method which will be used for solving the specific multi-criteria analysis problem depends on: the nature of the problem, the availability of information concerning a problem, the number of alternatives, as well as the knowledge, previous experience and preferences of the decision – maker [17].

Proposed MCDM methods for solving this paper's decision-making problem, the battery charging stations locations selection problem, are: CRITIC (Criteria Importance Through Intercriteria Correlation) and TOPSIS (Technique for the Order Preference by Similarity to Ideal Solution) method.

In order to evaluate the overall effectiveness of the candidate alternatives (battery charging stations locations), rank and select the most suitable stations locations, the primary objective of an MCDM methodology is to identify the relevant location selection criteria, assess the alternatives information relating to those criteria and develop methodologies for evaluating the significance of criteria [17, 18].

The weights of relevant location selection criteria are calculated by the CRITIC method, while, TOPSIS method is furthermore used for evaluation of alternatives (locations).

3.1. CRITIC Method

In the decision-making problems, criteria can be viewed as a source of information. The importance weight of criteria could reflect the amount of information contained in each of them [19]. The criteria weights obtained this way are „objective weights".

The CRITIC (Criteria Importance Through Intercriteria Correlation) method is a method for determining the objective criteria weights in the MCDM problem, introduced by Diakoulaki (1995) [20].

The criteria weights derived by this method combine the standard value deviation of the alternatives by each criterion and correlation coefficient between those criteria [20, 21].

The process of determining the criteria weights based on this method can be summarized in several steps.

Step 1. Calculate the transformations of performance values and obtain criteria vectors as follows ($K^{'}$ is the set of maximization criteria and $K^{"}$ is the set of minimization criteria):

$$r_{ij} = \frac{x_{ij} - x_j^-}{x_j^+ - x_j^-}, \forall K_j \in K^{'} \quad (1)$$

$$r_{ij} = \frac{x_j^+ - x_{ij}}{x_j^+ - x_j^-}, \forall K_j \in K^{"} \quad (2)$$

where $x_j^+, j = 1,..n$ are the greatest values for each criterion, while $x_j^-, j = 1,..n$ are the lowest values for each criterion.

Step 2. Calculate the standard deviation σ_j of each criterion using the corresponding vector:

$$\sigma_j = \sqrt{\frac{\sum_{i=1}^{m}(r_{ij} - \bar{r}_j)^2}{m}}, j = 1,..n \quad (3)$$

Step 3. For each pair of the criteria, the corelation coeficient is calculated as an indicator of their mutual dependance:

$$\rho_{jk} = \frac{\sum_{i=1}^{m}(r_{ij} - \bar{r}_j)(r_{ik} - r_k)}{\sqrt{\sum_{i=1}^{m}(r_{ij} - \bar{r}_j)\sum_{i=1}^{m}(r_{ij} - \bar{r}_k)^2}}, j,k = 1,..n \quad (4)$$

Step 4. The amount of information C_j contained in the criteria j is the determined in the following manner:

$$C_j = \sigma_j \sum_{k=1}^{n}(1 - \rho_{jk}), j = 1,..n \quad (5)$$

Step 5. Determine the criteria weights as follows:

$$w_j = \frac{C_j}{\sum_{j=1}^{n} C_j}, j = 1,..n \quad (6)$$

3.2. TOPSIS Method

TOPSIS (Technique for the Order Preference by Similarity to Ideal Solution) method was introduced by Hwang and Yoon (1981). The ordinary TOPSIS method is based on the concept that the best alternative should have the shortest Euclidian distance from the ideal solution (positive ideal solution – PIS) and at the same time the farthest from the anti-ideal solution (negative ideal solution – NIS). It is a method of compensatory aggregation that compares a set of alternatives by identifying weights for each criterion [15, 18].
TOPSIS method can be implemented using following steps:
Step 1. As it is presented, develop the average decision matrix (X):

$$X = \left[x_{ij}\right]_{n \times m} \quad (7)$$

Step 2. Determine the normalized decision matrix which elements are r_{ij} :

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \quad (8)$$

Step 3. Obtain the weighted normalized decision matrix which elements are v_{ij} by multiplying each column j of the normalized decision matrix by its asso
ciated weight w_j (obtained using CRITIC method for this paper purposes):

$$v_{ij} = r_{ij} \cdot w_j \quad (9)$$

Step 4. Determine the positive ideal and the negative ideal solutions:

$$\begin{aligned} V^+ &= (v_1^+, v_2^+, \ldots, v_n^+) = \{(\max_i \{v_{ij} | j \in B\}), (\min_i \{v_{ij} | j \in C\})\} \\ V^- &= (v_1^-, v_2^-, \ldots, v_n^-) = \{(\min_i \{v_{ij} | j \in B\}), (\max_i \{v_{ij} | j \in C\})\} \end{aligned} \quad (10)$$

where B and C are associated with the maximization and minimization criteria sets, respectively.
Step 5. The distance from the ideal and anti-ideal solutions are calculated for each alternatives using the two Eucledian distances as follows:

$$S_i^+ = \sqrt{\sum_{j=1}^{n} (v_{ij} - V_j^+)^2} \quad (11)$$

$$S_i^- = \sqrt{\sum_{j=1}^{n} (v_{ij} - V_j^-)^2} \quad (12)$$

Step 6. Calculate the relative closeness of the i-th alternative A_i to the positive ideal solution:

$$P_i = \frac{S_i^-}{S_i^+ + S_i^-} \quad (13)$$

The higher values of P_i indicate that the rank is better.

4 CASE STUDY – THE LOCATIONS SELECTION FOR THE BATTERY CHARGING STATIONS FOR TWO-WHEEL VEHICLES

The city of Niš is the third-largest city in Serbia and the administrative center of the Nišava District. According to the 2011 Census, the city proper area has a population of 187544 living on the urban city's surface of 266.77km^2.
The city of Niš, as the city with the rapid population growth, struggles in the field of urban mobility. Traffic congestion is a daily problem and the negative impact on the environment continues to grow. The current public transport system cannot handle the speed of the city's urbanization. Thus, the new, alternative, modern, sustainable, reliable, clean - „green" (fossil-fuel-free), way of transportation must be introduced.
One of the alternative means of transport is EVs (Electric Vehicles). The idea is the installation of a sufficient number of battery charging stations throughout the urban part of the city area (Figure 1).

***Fig. 1** Example of the EVBCS and the two-wheel EV*

Because there is the term „battery charging station", the type of electric vehicles that could use this „charging network" are BEVs (Battery Electric Vehicles). Given the current battery characteristics and current city's electric network capacity, two-Wheel Battery Electric Vehicles are proposed for this purpose (Figure 1).
This means that people could use some type of their two-wheels BEVs and drive it through the city and when it is required, to change their empty battery with a full battery on one of the batteries charging stations. Their empty battery left on the charging station (EVBCS) is going to charge and wait for the next user. This way cycle is repeating with every user at any station.
With the popularization of such way of transport and with its increase in users' acceptance (the main factor for acceptance is optimal EVBCSs layout) there will be less conventional vehicles present on the streets. This means that the increase of EVs in use will increase the positive effect on urban mobility and gigantic decrease the negative impact on the environment.
Determination of the optimal EVBCs positions (layout) inside the city represents the MCDM problem. The authors of this study have analyzed the core of this problem and the

results of that analysis were the criteria set and possible alternative solutions (different variants of EVBCSs positions). Alternatives and criteria which are presented in this study were formed based on the researcher's previous experience in this area, as well as, the knowledge of the city's urban mobility.

Four possible alternative solutions have been proposed [Figure 2-5]. Every alternative has its color mark for battery charging stations: A_1- red color mark; A_2- blue color mark; A_3- yellow color mark and A_4- green color mark. Also, every alternative has its number of stations and position characteristics.

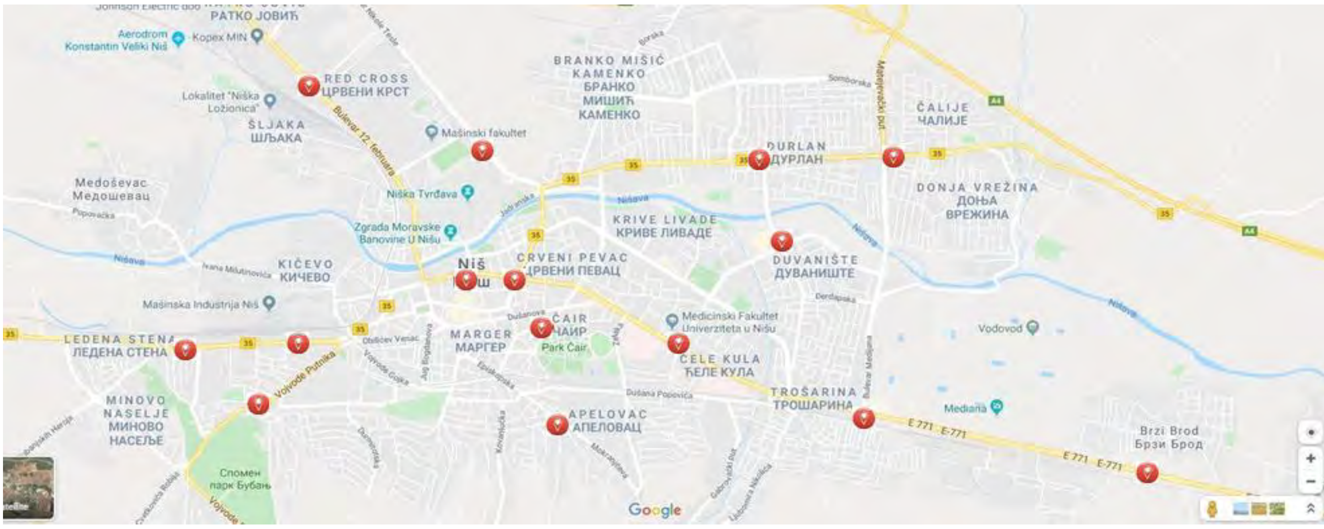

***Fig. 2** Alternative A_1*

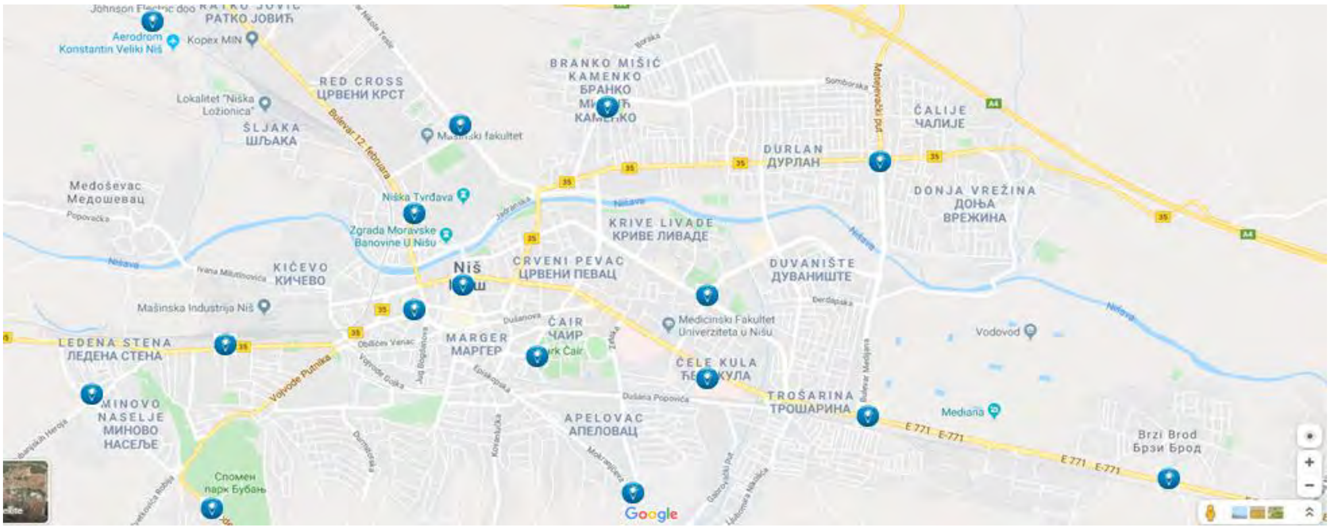

***Fig. 3** Alternative A_2*

The entire set of criteria consist of 4 criteria. Those criteria have been based on the factors that mostly affect the problem of the battery charging stations position. The criteria set have been chosen on the previous authors' experience – literature review, type of the problem, as well as the current urban situation in the city.

C_1 – Number of stations is the minimization criterion defined by the correct number of the battery charging stations on the layout. This number should be the lowest as possible, but great enough to cover the entire city's needs.

C_2 – Location expenses is also a minimization criterion which is in relation with the first criterion. This criterion depends on the land price in the exact city's municipality or its part (wheater it is about downtown or suburb). The criterion is based on grades.

C_3 – The average distance between the nearest battery charging stations is presented as the minimization criterion. The mean values were taken into account for each battery charging station position and they were calculated with the support of Google Maps.

C_4 – Traffic infrastructure proximity is the maximization criterion that represents the distance of battery charging stations from the bus stations, train stations, and airports, just in case of a need to use some other type of traffic. The criterion is based on grades.

The first three criteria are the minimization criteria where lower attribute values are performed. Tha last criterion is the maximization criterion where higher attribute values are desired. Two criteria, Location expanses (C_2) and Traffic infrastructure proximity (C_4) are qualitative and both are numerically represented using values 1-9 from the basic Saaty scale, as shown in Table 1.

Based on the described alternatives and defined criteria the decision matrix has been formed and presented in Table 1.

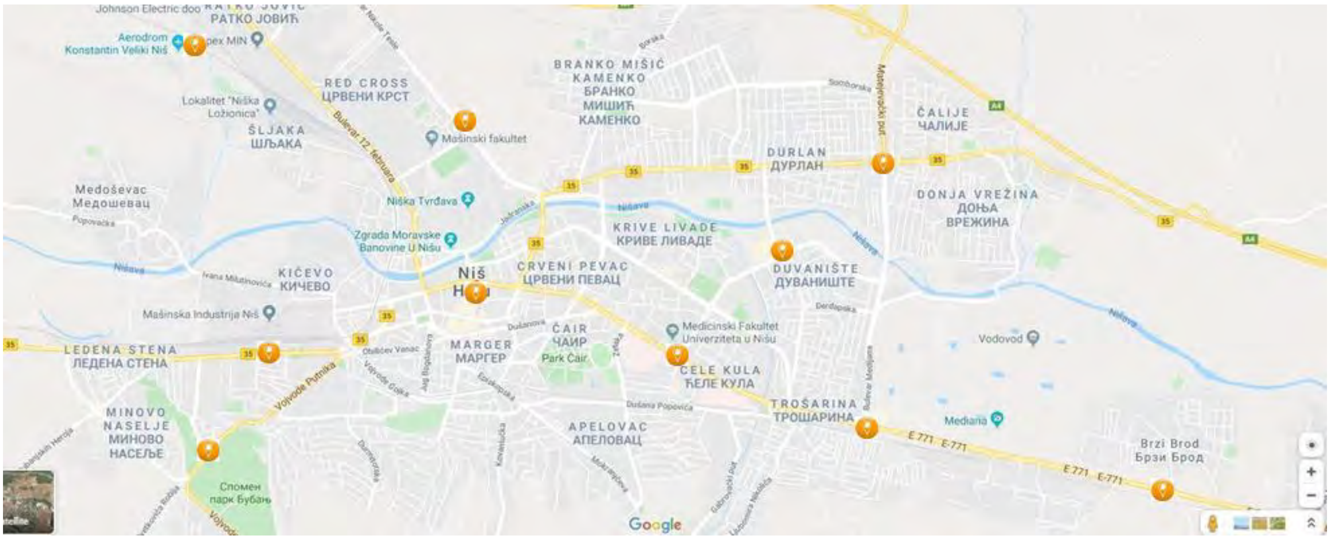

***Fig. 4** Alternative A_3*

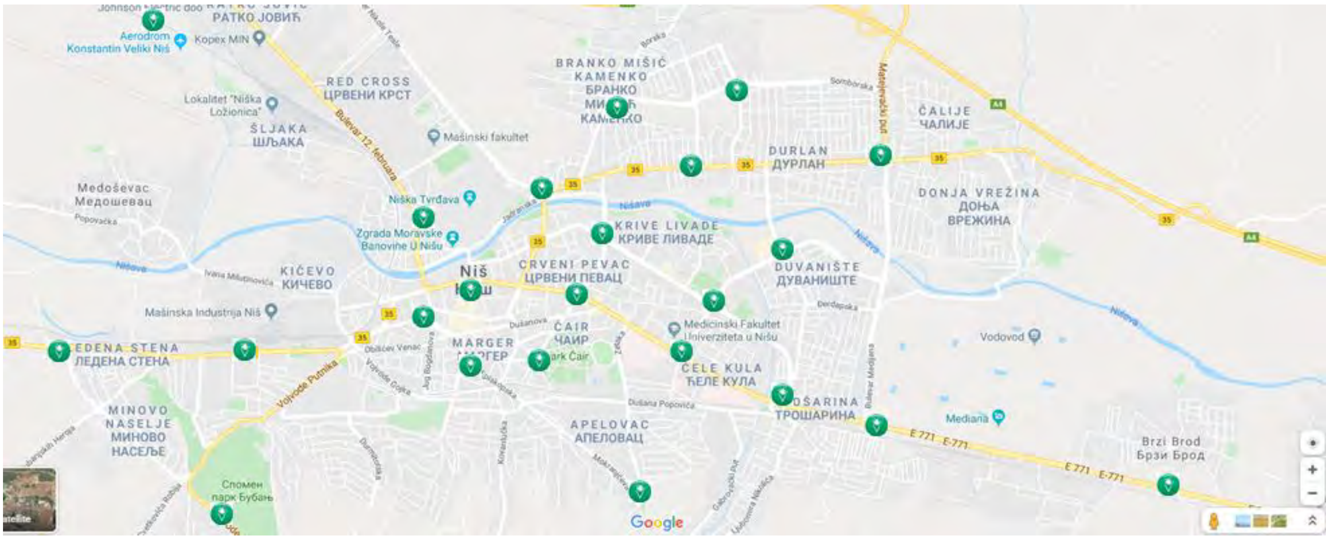

***Fig. 5** Alternative A_4*

Table 1. EVBCSs decision matrix

Criteria	C_1 [number]	C_2 [-]	C_3 [km]	C_4 [-]
Alternatives	min	min	min	max
A_1	15	5,2	2,11	6,8
A_2	16	5,8	2,21	8,2
A_3	10	3,4	2,69	5,8
A_4	23	9	1,95	9

For the evaluation process of the possible alternatives (EVBCSs locations), the hybrid MCDM method (CRITIC+TOPSIS) has been applied.
As described in Section 3.1, the CRITIC method has been used for determining criteria weights, as shown in Table 2.
Complete alternative evaluation and ranking have been done with the TOPSIS method as described in Section 3.2 and the assessment results are given in Table 3.

Table 2. Criteria weights obtained by CRITIC method

Criteria	C_1	C_2	C_3	C_4
w_j	0,237	0,238	0,254	0,270

Table 3. Complete rankings obtained by TOPSIS method

Alternatives	A_1	A_2	A_3	A_4
CRITIC+TOPSIS	0,609	0,587	0,667	0,333
Rang	2	3	1	4

According to this table, preference is given: Alternative A_3 > Alternative A_1 > Alternative A_2 > Alternative A_4. The best choice is Alternativ A_3 and the worst choice is Alternativ A_4.

5 CONCLUSION

The biggest problems which occur by the industry developments and the rapid growth in the human population are the increment of the number of automobiles in use. The result of this increment, the greenhouse gas emission rate has increased significantly and has caused global warming [2].
Many countries have started taking actions against global warming, and one of these actions is to promote the use of EVs. For those vehicles, to operate, a sustainable charging network is essential.
This research has demonstrated the applicability of the hybrid MCDM approach (CRTIC+TOPSIS) in the battery charging

stations' locations selection. The final results have shown the best-ranking score, which is Alternative A3. This alternative represents the best possible EVBCSs layout for two-wheels EVs on the territory of the city of Niš.

The improvement of this research from the MCDM point of view is in the better determination of the criteria weight and better evaluation of the possible alternatives by the use of the fuzzy MCDM methodology. The use of a greater set of criteria and more possible alternative solutions (acquired by e.g. survey) enable better and more reliable conversion from qualitative to quantitative and vice versa, as well as, the better final ranks.

The other way to improve this research can be found in the bigger sample. Evaluated alternative solutions were determined by the authors based on the urban mobility analysis in the city and based on their previous experience in this field. Beside more detailed problem analysis, the proposition is to perform a survey of the possible users of this kind of transportation system. This way, one or more, possible alternatives could be added into consideration.

Also, for some future endeavors, it is possible to observe the micro-level of this research. The final result (the best alternative solution) was chosen out of the four possible alternatives. This result was determined by observing the macro level of the problem. Now, concentrating on the chosen alternative solution A3 (micro-level observation) and simulating its work in the city, it is possible to make optimization/correction of positions and the number of battery charging stations.

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Contact address:
Jelena Mihajlović,
University of Niš
Faculty of Mechanical Engineering
18000 Niš
A. Medvedeva 14
E-mail: jelena.mihajlovic@masfak.ni.ac.rs

2. INTELLIGENT AND INNOVATIVE MATERIAL HANDLING EQUIPMENT AND TRANSPORTATION SYSTEMS

UNIVERSITY OF NIS FACULTY OF MECHANICAL ENGINEERING

THE SEVENTH INTERNATIONAL CONFERENCE
TRANSPORT AND LOGISTICS

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NON-INTEGRATED WORKING PLATFORMS USED IN CONJUNCTION WITH FORKLIFT TRUCKS – DILEMMAS, ANSWERS, AND BASIC GUIDANCE FOR DESIGN AND USE

Atila ZELIĆ [1]
Rastislav ŠOSTAKOV [1]
Dragan ŽIVANIĆ [1]
Nikola ILANKOVIĆ [1]

[1)] *University of Novi Sad, Faculty of Technical Sciences*

Abstract

As already known, counterbalance truck is intended for lifting materials. Lifting people with the non-integrated working platforms (NIWP) attached to forks is only allowed for the exceptional use. Considering the risk for a person performing maintenance works at height, such platform shall meet additional requirements concerning safety and health at work above all. In spite of numerous hazards arising during lifting persons in this way, in the majority of European countries there is no adequate regulation concerning precautions in design and usage of such platforms. On the basis of the previously mentioned, the authors of the paper point out dilemmas and key questions concerning this problem area. Besides, the general guidance concerning precautions in NIWP design and usage are given (based on the existing few regulative framework issues in industrial countries).

Key words: *non-integrated working platform, forklift truck, safety at work*

1 INTRODUCTION

Counterbalance forklift truck (further: CFT), powered by an internal combustion engine or battery operated motor, is provided for material handling by travelling a short distance within the premises of an industrial plant or a warehouse. It grips, transports and sets down the load usually directly with forks, but, depending on the load form and aggregate state, it can be provided with other attachable devices, [1]. But, there is often a need for elevating people, e.g. for the maintainance or construction works, electrical fitting, etc. User has relatively wide choice of disposable equipment for the work at height: simple movable ladders or scaffoldings are suitable for the lower work positions, and for the higher work positions mobile elevating working platform (further MEWP), loader crane or CFT with an integrated working platform (further IWP). IWP is an attachment with controls that are linked to and isolate the truck controls so that only a person on the platform can control the lift height of the platform and truck movements. Any movement of a loader crane is prevented (extended stabilizers!), consequently the corresponding controls on an IWP are needless, (Fig. 1).

Fig. 1 *Elevating persons, IWP attached to a loader crane*

As emphasized in [2], the choice of suitable means and manner of access depends on the nature, duration and frequency of work task to be executed at height, but, also on the equipmenmt at user's disposal.

As CFTs are in use in almost every domain of industry, they are often used for elevating workers to perform the interventions at a height of up to ≈ 6 m. As CFT&IWP combination is quite rare, non-integrated working platform (further NIWP) combined with a CFT or even with a crane is often the chosen solution. Regrettably, very often a person is elevated while standing on a wooden pallet on the forks, with no handhold, rails or screen guard against the contact with the parts of the lifting mechanism of a CFT.

Although the primary purpose of a CFT is elevating a load, or even people if it is provided with an IWP, elevating people with a CFT provided with a NIWP is allowed, too, but only under exceptional circumstances, and if both the platform and the forklift truck meet certain requirements.

According to the definition, [3], a NIWP (so called cage) is an equipment for use in conjunction with a CFT to elevate people so they can work at height. They have no controls that allow person on platform to control the platform lifting or the truck moving, and all the truck and platform movements are controlled by the truck operator (Fig. 2).

Fig. 2 *Elevating a person by means of a NIWP on a CFT, [2]*

According to previously mentioned, for performing routine, planned or predictable tasks of work at height (periodic maintenance, stocktaking, etc.), trucks intended merely to move persons to work positions where they are carrying out work from the working platform must be used, as they provide health and safety at work at height in the best way. Trucks with IWPs are suitable for the most of such tasks, as well. Usage of trucks with NIWPs is limited exclusively to executing exceptional, non-routine tasks. In the paper only NIWPs for lifting people by using CFT are considered.

2 HEALTH AND SAFETY REGULATIONS

In the course of discussions the Machinery Working Group of the Standing Committee for Directive on machinery came to a conclusion that a NIWP without controls on it does not meet the demands of the Directive on machinery, [4], and defined it as an equipment used for the purpose of lifting persons with machinery designed for lifting goods, [5]. So, NIWP is not in the scope of the Directive on machinery, consequently it must not bear the CE-marking in relation to this Directive. Therefore, there is no European norm on the design of a NIWP and it is subject to national legislation and/or practice.

Therefore, in each country authorized governmental bodies deside on the usage permission and limitations in usage of NIWPs. Of course, in aim to ensure the higher level of safety and health at work, the priority of usage is given to machines intended merely for lifting people (e.g. MEWPs), or to trucks with IWPs and some other purpose, as well, (e.g. loader cranes, rough terrain forklift trucks, etc.).

Consequently, such situation places significant technical barriers to the free trade within EU and makes interrelations between manufacturers, authorized inspectorates and users of NIWPs more difficult.

Although this way of elevating people has been estimated as a high-risk operation, in a lot of European countries (in Serbia, too) there is no adequate regulation that treats either the design or the safety measures concerning the usage of NIWPs for lifting people. In some European countries the usage of NIWPs for lifting people is absolutely suspended.

In Serbia there is no specific regulation considering safety at work even with cranes, fork lift trucks, storage and retrieval equipment, mobile elevating work platforms, mast climbing work platforms, lifting tables, vehicle lifts, suspended access equipment (platforms), etc. Nevertheless, ministries that have jurisdiction over the adoption of mentioned regulations, have taken the view that there is no need for adopting such regulations. In this situation, the usage of NIWPs for lifting people is neither allowed nor forbidden in Serbia. The effect of such situation is the increasing number of accidents due to ignorancy and misuse of CFTs with improvised platforms.

On the basis of the previously mentioned, authors tried to analyse the relevant questions concerning this matter. In the further text essential requirements concerning design and usage of CFT&NIWP for lifting people are presented, and certain dilemmas and obscurities are recognized. Also, some recommendations concerning the solution of the considered problem are proposed. The authors' approach to the matter is based on a small number of accessible sources, in the first place [2, 3, 6].

Demands concerning specific design details of NIWPc and CFTs and their mutual adjustment, conditions on their use, etc. somewhere notably vary from regulation to regulation. As the paper can not go into detail, only the basic common demands are presented.

3 LIMITATIONS OF NIWP USE

If national regulations allow that, NIWPs can be used occasionally if they represent a safer means of access for persons working at height than some other improvised solutions (e.g. ladders) or in cases when the use of an IWP for some reason is not possible.

According to [3], examples of occasional usage of NIWP in combination with a truck are:

- non-routine maintenance tasks for which would be an impractical solution to bring in a safer means (purpose-designed) access equipment;
- replacement of burn out light fittings, e.g. in a high-rise warehouse, but only when the task is not carried out as a part of periodical maintenance operations;
- tasks that would otherwise be carried out using some less safe means of access such as ledders, because it would be impractical to bring in a purpose-designed people lifting equipment due to the occasional character and short duration of the task (e.g. clening a gutter of roof);
- unexpected incident that could cause some ill effects, e.g. checking on a damage of a vital member of a latticed roof structure in a high workshop, susppected of causing an immediate risk of failure of a structure (e.g. collapse of the roof structure).

Daily, routine or in advance planned tasks (associated with production, stocktaking or periodical maintenance) are not treated as exceptional circumstances and consequently they can not be classified as cases of occasional use. Therefore, use of a CFT with a NIWP is not suitable for the activities like routine maintenance tasks, storage/retrieval in high-regal warehouses, or transfer of goods between levels.

NIWP is not suitable for use, [3], with:

- a truck that demands manual sequencing of the controls for lifting and tilting, in aim to maintain the working platform in a horizontal position during lifting;
- a truck with a mast that can cause wrong movement, e.g. due to sequencing problems during lowering;
- a truck that has an actual capacity of less then 1000 kg, unless its stability has been verified by testing or by calculations verified by empirical data (Note: Yet, some truck types of an actual capacity less then 1000 kg may be suitable for use with NIWPs, but truck manufacturer must confirm the IT&NIWP combination stability);
- a variable reach truck with the nominal lift height > 6 m (Note: The use of NIWP on it requires additional care due to the rough terrain on which these trucks are normally used and the type of the pneumatic tyres fitted);
- a pallet stacker with wrap-over forks type, and
- a truck operating in very narrow aisles, [6].

4 REQUIREMENTS FOR THE NIWP DESIGN

The platform floor must be enclosed, level, slip-resistant, with draining openings that prevent a ball Ø 15 mm to fall through, [2, 3, 6], capable to withstand 125 kg applied over any area 0,16 m^2 at any point, [3, 6], and a uniform pressure of 1500 N/m^2 over the whole area, [3], without permanent deformation. All the platform sides must be guarded, with usual measures for the top rail, toe board and intermediate rails (e.g. SRPS EN 13586), capable to withstand horizontal (from inner to outer), [3, 6], and vertical force, [3], of 900 N, or *n* persons×500 N, [3], without permanent deformation. The platform length (parallel to the fork arms) must not exceed 2×rated load centre distance of the CFT, and the platform width must not exceed the outside width over the truck load wheels by more than 250 mm either side, [3].

According to [3], the weight of the NIWP together with its load of people, tools, materials etc. should be not more than half of the actual capacity of the truck (when it is used for materials handling) with which it is intended to be used at the rated load centre distance and maximum lift height.

But, according to [2, 6], the stability and capacity of the CFT&NIWP combination is sufficient in case that:
– the NIWP floor area does not exceed 800×1200 mm;
– the NIWP is attached transversely to the longitudinal direction;
– the NIWP is fitted directly on the fork arms;
– the CFT is used on a level floor; and
– the CFT capacity is ≥ 5×weight of the NIWP together with its load of people, tools, materials etc.

The protection (screen/guard) against the contact with the moving parts of the truck lifting system must be ≥ 1,8 m heigh and wide enough to cover the width of the lifting gear or platform, whichever is the greater, and of sufficient size to prevent person from reaching the moving parts through, over or around the protection It must be in the form of a mesh with openings ≤ 50 mm in any direction, [6], in aim to provide the safety distances as given in SRPS EN ISO 13857, [3]. It must withstand the same horizontal and vertical forces as the platform sides.

A person on the platform must not be able to reach the truck controls.

It must be possible to fit an overhead guard to a NIWP when requested.

The gate must open inwards, upwards or sideways, must be selflocking and return automatically to the close position.

On a NIWP anchors must be provided to attach the body harness with a lanyard (that endures ≥ 3×user's body mass) to restrain a person from leaning over the rails, [3], or the 10 kN force with no permanent deformation, to prevent a person from falling down (fall arrest system) when leaning over the rails, [6]. The anchors must be adequately marked.

Suitably sized and located handholds must be fitted within the platform confines, that provide a gap of 90 mm between handhold and platform side (for use with a gloved hand).

A NIWP must be attached to the CFT fork arms (often), or a fork carriage (rarely), so that it is prevented from shifting, tipping or sliding in both the transverse and longitudinal directions. Fork mounted NIWP on its underside must have fork pockets to accommodate and fully enclose the fork armes (extended along ≥ 75% of the platform length) spaced at the widest practicable distance apart. The NIWP must be positively locked onto the CFT by a device that is included on the platform to retain it on the truck when in use. All loose device components should be secured to the NIWP. Fork pockets must be symmetrical about the NIWP centre line.

A NIWP must be provided with:
– an attached manufacturer's plate with basic information on platform and platform manufacturer;
– an attached manufacturer's plate easy readable from the truck opertor's position, with the important informations concerning obligatory checks and not allowed actions;
– instructions for use, maintenace, inspection, including the description of a CFT required for use with the NIWP (especially type and capacity).

5 ESSENTIAL SAFETY MEASURES FOR THE USE OF A CFT&NIWP COMBINATION

Before the use of a CFT&NIWP combination an authorized person must check its soundness, especially the correctness of setting and fastenning the platform onto the forks.

The work area must be clearly limited and marked (e.g. by warning traffic cones, light warnings, obstacles, etc.). The access of unauthorized persons, vehicles and movable machines to the area must be prevented. If necessary, all the other activities in the area of work must be suspended.

Before performing the work task, the CFT with the NIWP must be positioned strictly on a sound, level, clean terrain.

In aim to avoid undesired movements, before lifting the NIWP with persons truck operator must block the controls for truck movement and mast tilting, and apply the truck parking brake. If applicable, the truck operator must block the controls of attachment devices movements (tilt, or side shift), place the transmission in neutral position, and deploy the truck stabilizers and/or axle locking before lifting the platform.

An authorized person must check on the NIWP connection to the forks/fork carriage and the closed and locked position of the platform access gate.

The truck operator must lift/lower the NIWP strictly on the demand of the person on the platform. During the process the operator must maintain the sufficient distance between the platform and close objects in the environment in aim to avoid striking against traverses, pipe lines, electric cables, etc. All the movements must be performed very cautiously and slowly. The truck operator must not leave the control position on the truck as long as the platform with the person is elevated.

During lifting the platform, the truck mast must be in the strictly vertical position, i.e. neither mast tilting nor leveling the truck body are permitted. Although the truck must not perform movements with a person on the elevated platform, there are two exceptions to the rule:
– situations that demand minor corrective movements of the truck in aim to position the platform as precise as possible; and

– truck motion with the platform slightly elevated in aim to avoid the contact with the terrain (handholds must be provided within the platform sideguards, and the truck motion speed must be limited in dependence on the truck design, usually ≤ 16 km/h).

Standing area on the platform must not be raised by getting up onto the safeguard rails or by using some improvised means, e.g. foot-stools, trunks, etc. Person on the platform is not allowed to lean over the sideguard rails when the platform is elevated. But, if during performing the work task the need apears for workers to lean over the rail, they should wear harness and lanyards that are linked to the platform's harness anchorage point to prevent them from falling over the rails.

After the executed task of work on hight, the NIWP must be dismantled and laid away and stored in accordance with the instructions for use and maintenance. The condition of a platform must be visually checked before every repeated use. During regular periodical examinations and testings of a forklift truck, an authorized person must check on in details the corresponding NIWP, as well.

Apart from fulfilling all the usual demands, [3], the truck operator must be suitable and trained for lifting people using a NIWP. His level of training must be verified. An unambigious and unobstracted communication between the truck operator and the person on the platform assigned to give distinct commands, must be provided.

6 CONCLUSIONS

NIWP for use with industrial trucks or cranes is not covered with the Directive [4], so, it must not be CE-marked. The use of NIWPs is still an object of extensive expert studies. At the moment, regulations concerning its use differ sharply from country to country, and in some of them the use of industrial trucks with NIWPs is prohibited. After all, one opinion is the same in all the countries which allow the use of NIWPs at all, their use is only allowed under exceptional circumstances for executing strictly unforseen periodic transitory tasks.

As it can be comprehended on the basis of previously said, the main problems for the use of a truck with a NIWP for the work at height are:

– risks of:
  – loss of stability of the truck&NIWP combination;
  – fall of a person from the elevated NIWP;
  – injury of a person on the NIWP due to the contact with moving parts of the truck lifting mechanism;
  – injury of a person on the elevated NIWP by any truck movements;
  – miscommunication between a person on a NIWP and the truck operator;
  – design imperfection or failure of the NIWP structure;
  – failure of connections between the NIWP and forks or forks carriage;

– a need for:
  – the custom-made NIWP to fit into the specific truck;
  – the permanent presence of the truck operator while the NIWP is elevated;
  – the user's obligation to consult the truck manufacturer about attaching the defined NIWP to the specific truck type.

The design of a NIWP can not be entirely completed in advance, it must be adjusted to the design of the user's existing CFT, and even then that will not be always possible. That forces the NIWP manufacturer to produce custom-made platforms.

In Serbia there is no specific regulations concerning safety at work with forklift trucks, consequently for the use of CFTs (the same goes for cranes) with NIWPs, too. At the moment, the use of forklift trucks for lifting people is neither allowed, nor prohibited. It's high time these and a lot of other similar regulations (especially for lifting workers with cranes due to the very high level of risk, as unfortunately confirmed by the recent fatal accidents) were prepared and adopted.

In view of the fact that the year 2019 has been proclaimed in Serbia *The year of safety and health at work*, and with regard to some fatal accidents at work with NIWPs (even in 2019), and numerous regulations that consider safety at work with cranes, industrial trucks, movable platforms, etc. (apart from European Norms) in relevant European countries, the paper should encourage the authorities in Serbia to reconsider their opinion that the existing regulations are quite sufficient to ensure safety at work with cranes, industrial trucks, movable platforms, etc.

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Contact address:
Atila Zelić
University of Novi Sad
Faculty of Technical Sciences
21000 Novi Sad, Serbia
Trg Dositeja Obradovića 6
e-mail: zelic@uns.ac.rs

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POSSIBILITIES OF MATERIAL FLOW PROPAGATION THROUGH CONVEYOR LOADING DEVICES

Dragan ŽIVANIĆ [1]
Nikola ILANKOVIĆ [2]
Atila ZELIĆ [3]

[1)] *Assoc. Prof., Faculty of Technical Sciences, Novi Sad*
[2)] *Assist.Master, Faculty of Technical Sciences, Novi Sad*
[3)] *Assist. Prof., Faculty of Technical Sciences, Novi Sad*

Abstract

Conveyor loading devices must be designed to accommodate and facilitate the flow of bulk materials. Creating a loading device that would work properly in every condition of bulk material is almost impossible. However, changes in material properties and system demand can create problems in the flow of bulk material. Bulk materials with high moisture content can adhere to walls of the loading devices or even freeze during winter operations. Continuous operation can even further tighten the bulk material to the wall of the loading device. Bulk materials can also change characteristics during transport or some technological operations. In some cases, the loading devices can be completely blocked by just a small change in any material characteristics. In order to overcome these problems, a variety of devices called flow aids are utilized. Flow aid devices are mechanisms used to stimulate or enhance the movement of bulk materials through loading devices. Because they affect conveyor loading, flow aid devices can also impact on spillage and dust generation. In this paper various methods for improving the flow of material through loading devices are presented.

Key words: *material flow, loading devices, conveyors, flow aids.*

1 INTRODUCTION

Material loading method on the belt conveyor has great impact on its lifetime, especially on the lifetime of the belt. The shape of the loading device depends on the material that is transported, primarily from its granulometric composition, bulk weight and abrasiveness. [2]

Load hoppers are used most often for loading bulk material, figure 1. Loading hopper has to ensure adequate material behavior during its descending on the belt and in the same time to prevent clogging, too much dust, material spillage, and excessive impacts. Feeding area of the belt conveyor has to fulfill following tasks:

- to ensure adequate transfer of bulk material at specified doses without clogging - material feeding;
- to provide protection for workers;
- to ensure lesser spillage of the material;
- to provide a possibility of returning deposited or spilled material to the main stream i.e. to the conveyor belt;
- to be easy to maintain and use.

Fig. 1 *Loading hopper display*

2 MATERIAL FEEDING

Basic function of a feeding hopper is to ensure material feeding on the belt in certain and given levels. Material has to be equally and constantly feeded on the feeding location – under the outlet of the feeding hopper, but in some situations, there may be considerable impacts of material on the belt whose consequences may be felt on the functioning of the entire conveyor. For this reason, cradles are placed at the loading area below the belt, figure 2.

Fig. 2 *Cradlers used instead of idlers in the conveyor loading area*

Those impacts are capable with their force to lead to overload of certain parts of the conveyor, before all the drive mechanism or, if they happen periodically, they can lead to belt misalignment. Also, frequent material clogging can occur if the cross section of the hopper outlet is small.
Most of the feeding hoppers are designed by the "thumb" rule, they are designed with very little research done before. Therefore, hoppers have problems with material clogging and wear and tear issues with their walls. In order to solve these problems, a new method was developed called DEM – Discrete Element Modeling Method. The method is very similar to molecular dynamics. It is a numerical method

which calculates differential equations for each particle of the bulk load and by doing that, it simulates material flow. Also, DEM software has FEM – Finite Element Method included which is used for the calculation of construction wear.

On a feeding hopper, shown in figure 3, the top and sides were covered and protected not only in the feeding area but also in front and at a certain length behind the feeding point. This method of feeding achieves adequate protection of workers in the environment, reduces noise and prevents material spillage. Of course, it should also be mentioned that this is not the only protection for workers in this area but, if any particularities regarding the hazard are identified, they are eliminated by some other type of protective elements or devices (limiters, fences, optical, thermal sensors, warning signs, etc.). In figure 4 additional protection in the feeding area is shown. [1]

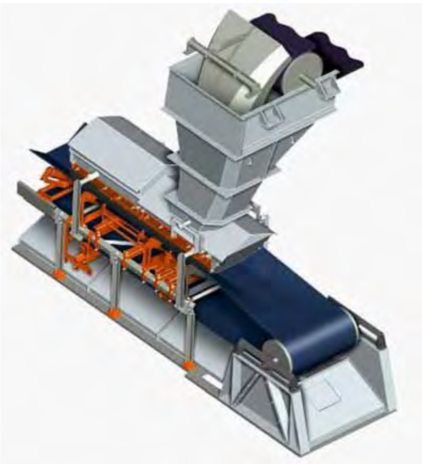

Fig. 3 *Illustration of a modern feeding area [1]*

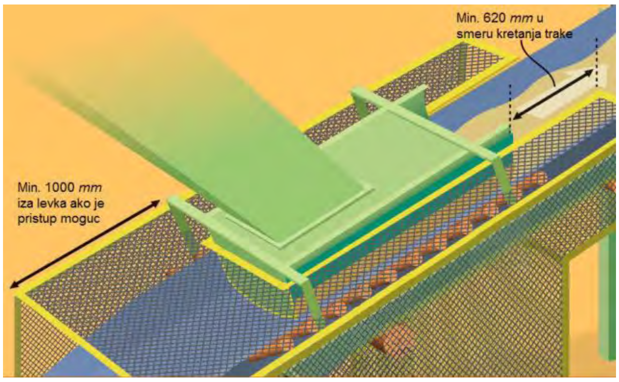

Fig. 4 *Additional protection in the feeding area*

2.1 Reduction of feeding material spillage

Reduction of feeding material spillage is perhaps the most important condition for proper and correct work of a belt conveyor, but often it represents the biggest problem. Irregularities in this domain lead to huge amounts of dust which represents a big problem for workers and the equipment nearby. [4]

There is a number of related causes involved in dust creation and material clogging, but the primary reason is the off-center feeding of the material onto the conveyor belt. The geometry and dimensions of the opening of the feeding hopper's outlet is very important in order to ensure proper access and removal during maintenance, and at the same time to provide sufficient volume of space that, if the off-center feeding of the material is occurring, it could prevent the appearance of dust, i.e. to provide an adequate amount of airflow, figure 5.

Fig. 5 *Cross-section of the feeding hopper where dust-seals can be seen*

Also, the off-center feeding of the material on the conveyor belt causes not only the problem of dust formation but also the occurrence of belt misalignment due to the uneven loading on the belt, figure 6. Solutions are found in the additional common application of self-adjusting rollers and other systems for leveling the material on the belt in the feeding area, figure 7. It is also possible to apply deflectors, reinforcements, grizzly bars, air cannons or rock boxes inside the feeding funnels themselves.

Fig. 6 *Off-center feeding of the material on the belt (left) and belt misalignment (right)*

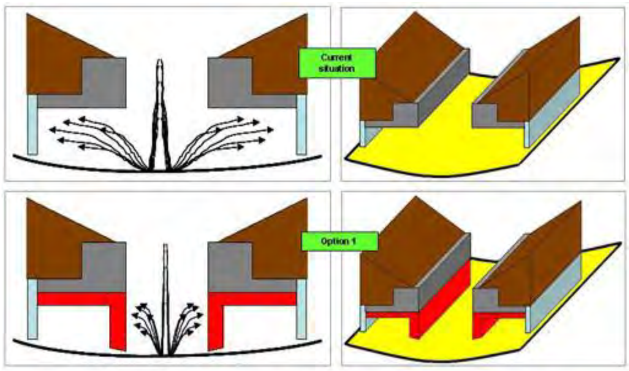

Fig. 7 *Material spillage during loading on the belt and possible spillage reduction solutions*

2.2 The return of the deposited or spilled material to the main flow

Belt cleaners must be installed near the unloading pulley. They remove the remaining material that is stuck to the belt after the point of discharge. One possible option of the belt cleaner is shown in figure 8.

Fig. 8 *Belt cleaner*

In order to prevent the removed material collecting on the main hopper walls or other components, it is necessary to install an extra-large hopper, with steep sides - it is desirable that due to the high adhesion, these sides should be at a large or even vertical angle, which will close the entire cleaning system and allow the return of removed material to the main flow. [1] Also, to make the whole system work properly, it is sometimes necessary to install oversized hoppers, with sides that have low coefficient of friction or some auxiliary devices such as vibrators, air cannons or scavenger conveyors, and some of them are shown in figure 9, figure 10 and figure 11.

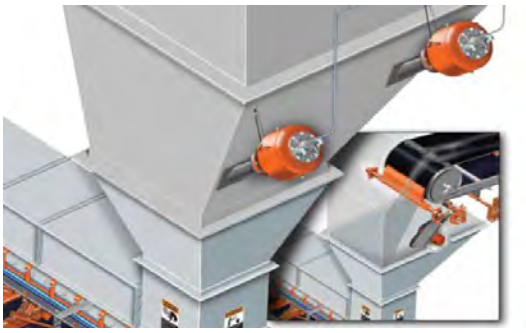

Fig. 9 *Air cannons installed on the feeding hopper*

Fig. 10 *Air cannons installed on the feeding hopper by the Martin Engineering Company UK*

Fig. 11 *Scavenger conveyor*

Only a feeding hopper that is designed and constructed to be easily maintained and cleaned will be maintained and cleaned feeding hopper. By doing so, one should always strive to design the hopper so that parts can be easily removed and parts that need maintenance or cleaning can be easily accessed. Of course, this is not always the case and much more often when they are used indoors, there is the presence of certain pipes, conduits, walls, because more often the whole conveyor is designed in relation to the room already given. Thus, at the outset, it is necessary to anticipate the need for maintenance and in places that are hard to reach to design possible ladders, openings, etc., on the hopper.

3 DESIGN OF FEEDING HOPPERS

Conventional feeding hoppers are consisted of several basic parts, shown in figure 12: [1]

- A Head chute - the part that surrounds the area around the end pulley of the conveyor in front of the hopper;
- B Drop chute - the part where the material is in free fall;
- C Loading Chute or Load Area - The part where the material comes into contact with the conveyor belt;
- D Settling zone - although not part of the feeding hopper, it is associated with it and plays a role in blocking and controlling the spread of newly formed dust.

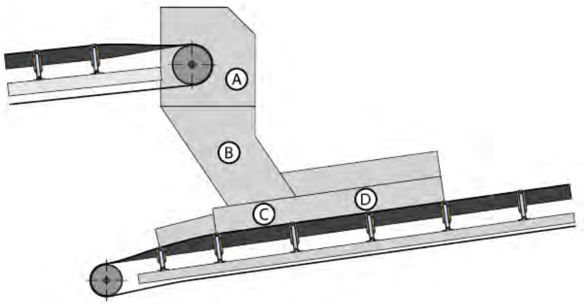

Fig. 12 *Feeding hopper with its sections*

The trajectory of the material depends on the speed of the belt, the angle of inclination of the feeding belt and the profile of the material on the belt. The trajectory is drawn on today's feeding hoppers and serves to monitor the material at first release and to determine whether and where the material will strike the wall of the upper part, and from there, by the previous realization of the design, it is considered that the material goes from above to down like a beam of light, reflecting from wall to wall. [2]

Proper use of the already mentioned Discrete Element Modeling Method (DEM) achieves an adequate path so that the material, after the first impact, is not guaranteed to have a free fall on the belt, and falling heights, i.e. the heights between stages are designed so as to provide a minimum amount of generated dust, while also reducing the destruction of the structure material. Also, in such a way of feeding, the belt is affected less by dynamic shocks.

The distance between the driven pulley of the feeding conveyor before the upper part of the feeding hopper and the first wall of the feeding hopper should ensure a safe entrance of the material into the hopper without the possibility of some small pieces passing between, which is usually about 50 to 75 mm, but of course with these dimensions, it has to be thought about the accessibility for maintenance of the driven pulley and the shaft bearings. As one of the improvements in terms of controlled and reduced dust formation, proper on-center loading of the material, minor damage to the belt and material of the construction, the so-called “hood and spoon” hoppers are used, shown in figure 13. Namely, they must be at an adequate angle of inclination to avoid possible clogging of the material between the walls.

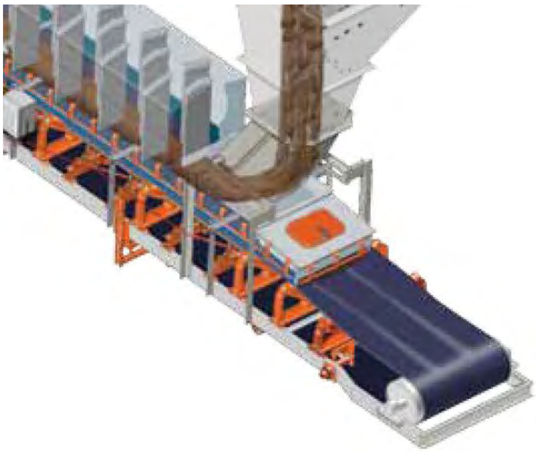

Fig. 13 *The end of the feeding hopper in the shape of a “hood and spoon”*

It is commonly accepted that the cross-section of the drop part of the feeder should be a minimum of four times the cross-section area of the material profile. The minimum dimensions for width and/or depth should be at least 2.5 times the largest lump expected to pass through the chute. In some cases, where the bulk material is uniform in size and free flowing, these ratios can be reduced, especially when the chute is engineered using the specific properties of the bulk material being conveyed.
The feeding hopper width should be designed to maintain the minimum belt edge necessary for sealing and accommodating misalignment.
The most common mistake that can be made during this phase of hopper design is making too abrupt a transition between the drop chute and the loading chute, creating hopper wall angles that promote buildup leading to material clogging. Current design practice is to use angles of 60 degrees, preferably 75 degrees. [3]

3.1 Deflectors

Deflectors, shown in figure 14, are used for the control of the material flow and to soften impacts thus reducing dynamic loads and damage to the belt. They are positioned

Fig. 14 *Deflector placed in the upper part of the feeding hopper*

in the upper part of the feeding hopper in the place where the first hit of the material on the hopper wall would occur.
It is desirable that their position can be adjusted within certain limits, as most often the first placement does not prove to be the most effective. The problem with off-center material loading on the belt can be reduced by placing a deflector on the inside at the bottom of the feeding hopper near the belt.
The placement of one or more impact plates and deflectors is sometimes necessary to soften the impact of the material. Deflectors should be given special care while maintenance because they may be causing jams or clogging in the feeding hopper. [3]

3.2 Grizzly bars

Grizzly bars, also called scalping bars, shown in figure 15, represent the first stage of defense of the conveyor belt and all elements before the belt from large pieces of material. The remaining pieces are rolled aside as they are stopped. They are often used in places where material is unloaded directly from a truck.

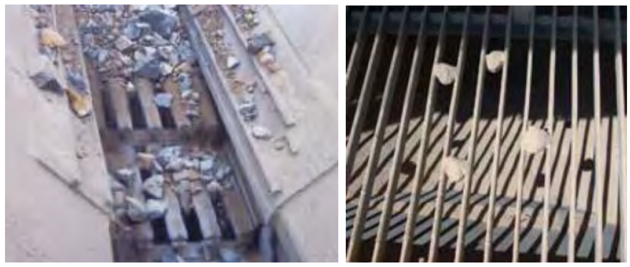

Fig. 15 *Grizzly bars*

3.3 Rock boxes

In the case of feeding materials such as sand, gravel, larger stones, or generally material that does not change the physical and flow properties, the most commonly used are rock boxes or rock ladders, shown in figure 16.

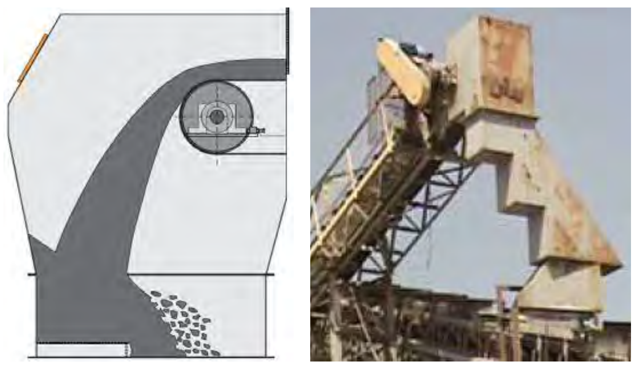

Fig. 16 *Rock box (left) and a rock ladder (right)*

They function on the principle that a certain amount of material is "sacrificed" by building-up on a stepped section forming a pile, thus protecting the load-bearing structure from abrasion, and the creation of a large pile makes fall heights of the material acceptable, thus reducing noise and dust formation. In the case of rock ladders, they are designed so that no height difference in stages reaches no more than 1.5 to 2 m.

3.4 Impact plates or grids

Impact plates are used for diverting material flow and absorption of impacts that hit the inner side of feeding hopper walls. Some impact grids are designed to catch material to develop a material-on-material impact that preserves the hopper walls. Proper selection of materials used for plates and their adequate positioning can increase the lifespan of these wear elements.

3.5 Wear liners

In spite of all the above elements of protection of the feeding hopper, damage and deterioration of the walls of the hopper are still occurring, so a different approach is taken. Inside hoppers themselves, so-called self-sacrificial load-bearing liners are placed on their walls, which have the role of wearing out instead of walls. The material used for them must be abrasion resistant and has to enhance the material flow by their presence.

3.6 Vibrators

The role of vibrators is to reduce the cohesion between transported material and walls of the hopper. Also, they reduce cohesion between material particles. By doing that, they increase the material flow. The proper vibration level depends on particle size. The smaller the particle, the better it responds to higher vibration frequencies. The relationship between amplitude of vibration and the bulk material is based on cohesive and adhesive forces. As the particle size increases, the amplitude required to cause the bulk material to move increases. Particles that are fine and free flowing tend to respond well to small amplitudes of vibration. Larger free-flowing particles respond better to large amplitudes. Particles that are sticky tend to build up in solid masses that respond well to low-frequency high-amplitude vibration. The direction of the rotation or stroke of vibrator's mass should be in the direction of the desired material flow.

Linear vibrators

Traditional means of overcoming adhesive forces between the material and walls were acts of pounding with heavy hammers on the outside surface of a hopper which is shown in figure 17. The problem of this solutions is the heavy damage that hopper walls suffer, figure 18. Also, workers suffered injuries.

***Fig. 17** Traditional hammer pounding*

***Fig. 18** Damages of the outside surface of hoppers*

For this purpose, to protect workers, but also because of the long period of large flows and various materials, which only made "wall pounding" useless, the pneumatic linear vibrators were introduced shown in figure 19.

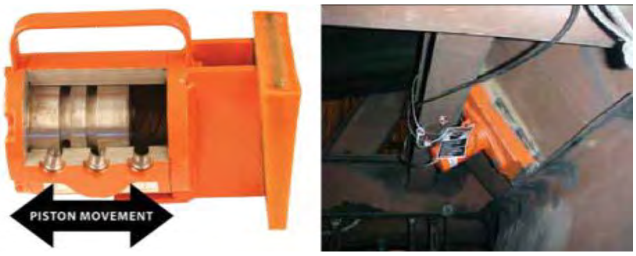

***Fig. 19** Linear pneumatic vibrator*

In some solutions, an industrial-air linear vibrator strikes the hopper wall directly, while in other solutions, by using its own sufficiently large and massive mass, provides an adequate level of vibration, thereby breaking the bond between the material and the hopper wall. Their installation takes place in places where either the deposition of the material is expected or determined. The linear vibrator is designed to break down sediments formed by sticky, very moist, coarse and rough materials.
How to determine if a linear type of vibrator is suitable for breaking the formed sediment of the material? On the spot, a piece of material is taken and a lump is made in the hand. If the material retained the shape of the ball when opening the fist, then a linear vibrator is probably the best choice. The linear vibrator itself is selected for each system separately based on the weight and characteristics of the material inside the hopper. The usual approach is to install a vibrator to fit a 1 N for 1 kg material. This approach is acceptable, but only for one narrow segment of materials that are considered to be liquid and have a density of less than 1440 kg/m^3. Of course, more force would be needed to break down the deposits of material that is of higher density or humidity.

Rotary vibrators

Unlike linear vibrators, rotary vibrators do not use direct pounds but generate high vibration intensities using an eccentrically mounted mass, which can be driven by air current (pneumatic vibrators), hydraulic oil (hydraulic vibrators) or eccentrically mounted mass at the end of the AC motor shaft (electromotor driven vibrators). They are shown in figure 20.

Fig. 20 *Pneumatic, hydraulic and electromotor driven rotary vibrators*

For reasons of high vibration intensities, rotary vibrators must be installed in places previously reinforced to prevent cracks or even severe damages within the structure. They are also installed on the mounting plate, which plays the role of accepting the mass of the device but also spreading vibrations to a larger surface. It is common to mount at 1/4 to 1/3 the height of the overall structure. The choice of rotary vibrators is such that the ratio of output force to mass of material inside the hopper is usually taken as 1:10.

3.7 Air cannons

Air cannons are another way of breaking down the accumulated deposits inside the feeding hopper, while operating on the principle of compressed air. Air cannons are simply reservoirs of stored compressed air with fast-acting discharge valves. When valves are activated, the air escapes swiftly, creating a wide area of influence. By providing positive pressure in the hopper, air guns are very acceptable for the reason that they allow dust to be removed from the hopper. It is possible to install one tank with one or more nozzles.

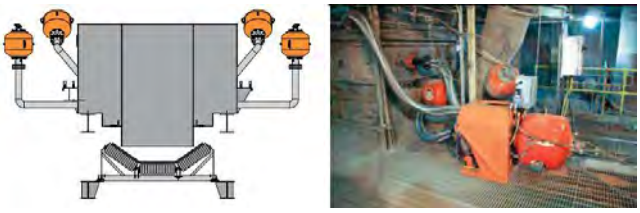

Fig. 21 *Air cannon with one tank per nozzle (left) and air cannon with one tank with number of discharge nozzles (right)*

The number of air cannons installed per hopper depends on the size and shape of the hopper itself, as well as the nature of the formation of material deposits. Usually, one air cannon is capable of serving 1.5 to 2 m^2, with an acceptable air volume of 50 l.

Another solution is also possible where electronically connected air cannons with computers are automatically activated at a time interval, all without the need for monitoring by workers.

4 CONCLUSION

Continuous loading of material onto the belt conveyor is a prerequisite for the proper operation of the conveyor. In addition to providing the required capacity, proper loading protects the belt, extends its life, and also the operation of all conveyor components is quiet with less noise and less load.

In order to ensure this, it is necessary to define at the design stage the appropriate geometry of the loading hopper, and in the operation of the conveyor, apply some of the described devices.

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Contact address:
Dragan Živanić
Fakultet tehničkih nauka, Novi Sad
21000 Novi Sad
Trg Dositeja Obradovića 6
E-mail: zivanic@uns.ac.rs

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ZIPLINE COMPUTATIONAL MODEL FORMING AND IMPACT OF INFLUENTIAL SIZES

Radomir ĐOKIĆ [1]
Jovan VLADIĆ [1]
Tanasije JOJIĆ [1]

[1] *University of Novi Sad: Faculty of Technical Sciences, Department of Mechanization and Design Engineering*

Abstract

At first sight zipline represents a very simple system. It is consisted of tightened rope by which the person is carried by high speed travelling trolley with aim of causing increasing excitement. For quality design, production and safe use of zipline, it is necessary to perform a detailed determining of route selection, rope type and loads for pylons dimensioning. Further, it is necessary to analyse persons kinematic parameters in dependence from a range of influential sizes such as person's weight, trajectory inclination angle, wheel resistance, air resistance, wind, etc. This is especially important in case of long span and extreme inclination angle. A computational model is based on theoretical background which is presented in this paper. Computational model enables determination of so-called "driving" characteristic of zipline. The results are obtained as an illustration of conducted analysis which was based on the theoretical setting for the relevant model. The analysis was made by computer simulations for specific conditions of zipline whose installation was planned on Fruška Gora.

Key words*: Zipline, Catenary, Computation Model, Computer Simulation, Motion Resistance*

1 INTRODUCTION

The term "zipline" represents a system containing a tightened steel rope by which a person is carried by high speed travelling trolley. The trolley and the person are moving under the influence of their own weight. The main aim is causing increasing excitement, as in so-called adrenaline sports. Ziplines expanded over the past two decades with construction in various locations such as hilly areas, parks, lakes, bridges, the city cores, etc, [1]. Figure 1 shows a schematic representation of a zipline with main notions.

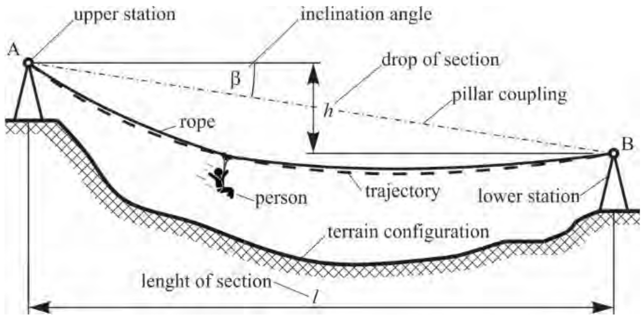

Fig. 1 *Schematic representation of zipline*

From usage and safety viewpoint, the most interesting kinematic parameters are maximum velocity and acceleration, travelling time, range and velocity at the end of the section (velocity at the limiter). The most significant size that influences those parameters is the inclination angle (β). For inclination angles larger than 10°, high velocities are achieved at the section, but also at the entry of the lower station which is a significant problem for stopping the person safely. In cases of inclination angles lower than 5°, there is a problem with arriving to the lower station, especially in cases of unfavorable wind direction or changes of the area exposed to the air flow (body position, spreading of hands, etc) during movement. For such cases, there is often a need to "pull out" the person from the section.

2 THEORETICAL BACKGROUND AND COMPUTATIONAL MODEL FOR ZIPLINE ANALYSIS

The computational model is based on the catenary theory which represents an elastic flexible thread freely suspended between two supports located on the horizontal (l) and vertical (h) distance and loaded with its own weight [2].
The catenary equation, in a well-known form, is:

$$y = C \cdot \mathrm{ch}\left(\frac{x}{C}\right) \tag{1}$$

where catenary parameter (C) is obtained as:

$$C = \frac{H}{q}$$

where:

H - horizontal component of the rope force,
q – own weight of rope.

Catenary theory provides accurate solutions, but as the use of hyperbolic functions is relatively complicated for engineering practice, the catenary is replaced by the appropriate parabola. Figure 2 shows the possibility of replacing the catenary with a parabola. Errors in the size of the deflections made by this approximation are 2 ÷ 3%. Accuracy can be increased by introducing a correction coefficient (k).
Parabola method obtains an equation:

$$y = \frac{q \cdot x \cdot (l - x)}{2 \cdot H \cdot \cos\beta} \cdot k + x \cdot tg\beta \tag{2}$$

where:

$$k = 1 + \frac{\cos^2\beta}{p} \cdot \left[\frac{1}{p} \cdot \left(x^2 - l \cdot x + \frac{l^2}{2} \right) - 2 \cdot (l - 2x) \cdot tg\beta \right]$$ - correction coefficient,

$p = \frac{H}{q} \cdot \cos\beta$ - parabola parameter.

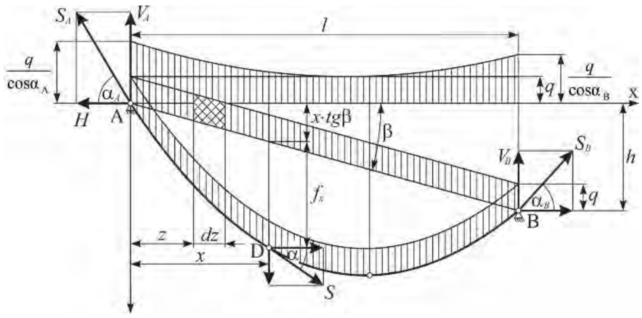

***Fig. 2** Parabola method*

In case of using a steel rope, whose supports are at different heights, loaded with its own weight and concentrated loads, as shown on Figure 3, the equation of the trajectory of a person can be represented as:

$$y = x \cdot \mathrm{tg}\beta + f_x \qquad (3)$$

where the deflection at a distance x_D at which the load is acting is represented as:

$$f_D = \frac{x_D}{l \cdot H} \cdot \left[Q \cdot (l - x_D) + \frac{q \cdot (l - x_D)}{\cos\beta} \cdot \frac{l}{2} \right] \qquad (4)$$

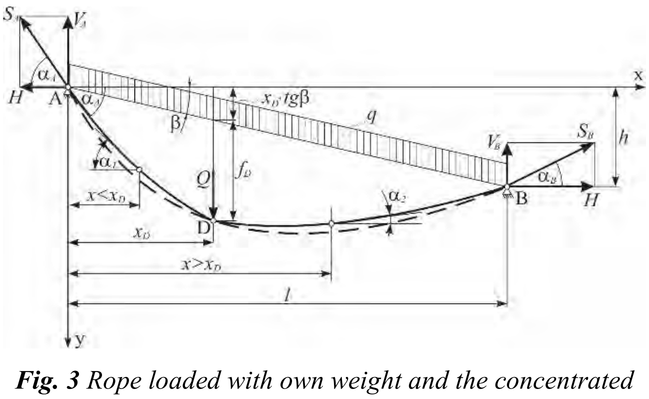

***Fig. 3** Rope loaded with own weight and the concentrated load, [3]*

Usually, for short ziplines, both ends of the rope are anchored, but for ziplines with larger spans the ropes are anchored at one end and tightened with weight at the other. Realization of zipline with both-sided anchorage is easy, which is the reason why it is often applied for short ziplines (from "one three to the other"), but it represents a statically indeterminate system. In such case, the tension rope force changes considerably with the load moving, and additionally depends on the rope elasticity and current temperature. These are the main reasons why the case of a rope that is anchored at one end, and tightened with weight at the other is generally more favourable, but the solution requires more space on the pillar and the system is more expensive which is justifiable only for large span ziplines. Furthermore, this paper will focus only on case of a rope that is anchored at one end and tightened with weight at other.

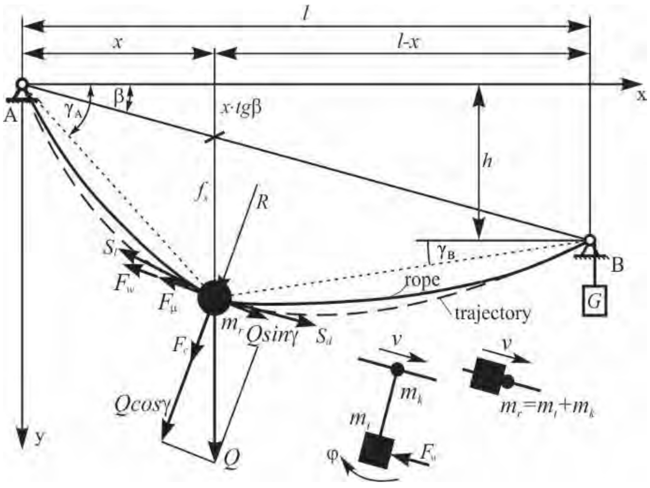

***Fig. 4** Computational model of a zipline*

The relevant computational model will be formed by neglecting small quantities of high order. The so-called static trajectory of movement is determined by expressions (3) and (4). Rope oscillation in vertical plane is relatively small according to [4], [5] and [6] and can be neglected in case of "shallow" terrain and a system where the rope is anchored at one end and tensioned with weight at the other.

Person connected with trolley forms a mathematical pendulum. If the length of the connecting belts is short, the effect of the swing can also be neglected as well as the influence of the centrifugal force due to the large radius of the trajectory curvature.

In accordance to that, the computational model, shown on figure 4, can be represented as a movement of a concentrated mass along the trajectory determined for static conditions, [7]. The air resistance and rolling resistance are acting on the concentrated mass while moving in the direction which is always opposite to the direction of movement.

Every wheel that is rolling along deformable surface has a resistance component due the friction in wheel bearings and due to deformation of contact surfaces. Figure 5 shows a wheel that is rolling along the rope and has an additional resistance component due rope stiffness. Unlike a perfectly flexible rope, the real rope will not take the position of the tangents behind and in front of the wheel, which can be seen as a "wrinkling" of rope in front of the wheel, [8].

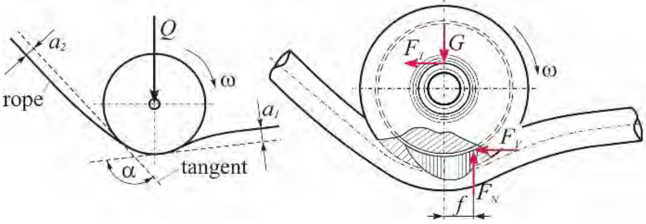

***Fig. 5** Model of wheel rolling along steel rope*

Movement resistance of wheel that is rolling along steel rope can be determined by the expression:

$$F_\mu = \mu \cdot \sum G = \left(\mu_0 \cdot \frac{d}{D} + 2 \cdot \frac{f}{D} \right) \cdot \sum G \qquad (5)$$

where:

- μ - total resistance coefficient,
- μ_0 - bearing friction coefficient,
- d – bearing diameter,
- D – wheel diameter,
- f – lever arm of rolling torque,
- $\sum G$ - sum of vertical forces.

Air resistance for person lowering on zipline is calculated as:

$$F_w = c_w \cdot A \cdot \frac{\rho \cdot (v \pm v_v)^n}{2} \qquad (6)$$

where the dimensionless exponent (n) according to [9] has values of:

- n=1 for velocities smaller than 1 m/s,
- n=2 for velocities between 1 m/s and 300 m/s,
- n=3 for velocities greater than 300 m/s.

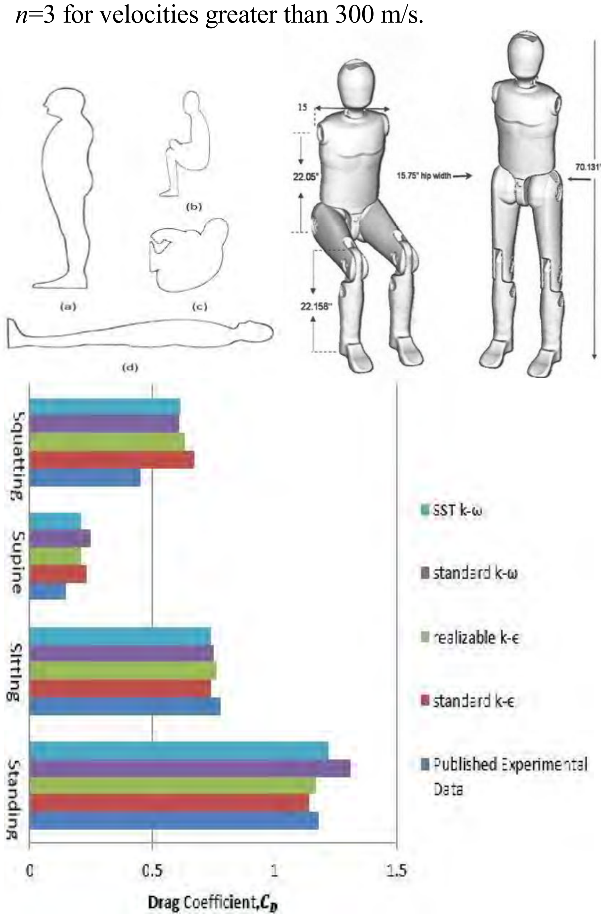

***Fig. 6** Determining drag coefficient and areas*

Values of drag coefficient (c_w) are determined experimentally. According to [10], the values for different lowering positions are:

- c_w =0,6 - for sitting position,
- c_w =0,4 - for half-sitting position,
- c_w =0,2 - for lying position.

Areas exposed to air flow (A) are depending on the person's size and body position. Based on dimensions shown on figure 6, the areas of person that is lowering the body to the seated position are approximated as:

- A=0,25 m^2 for person weighing less than 70 kg
- A=0,3 m^2 for person weighing between 70 kg and 110 kg,
- A=0,4 m^2 for person weighing more than 110 kg.

3 RESULTS OF ANALYSIS

This heading presents an analysis results for an example of a zipline with a section length of 1214 m and drop of 122 m (therefore with inclination angle of 5,7°) whose installation was planned on Fruška Gora in Serbia, [11].

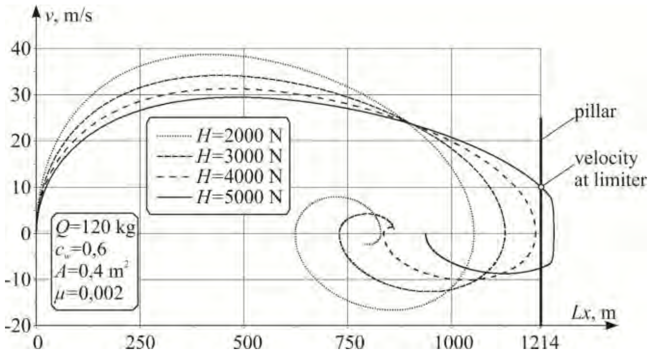

***Fig. 7** Diagram of velocity for different values of tension rope force*

Diagram shown on figure 7 represents a change of velocity as function of horizontal distance between pillars (section length) for person's weighing 120 kg and different values of tension rope force. It is notable that increase of tension rope force increases reach, but reduces maximal achieved velocity.

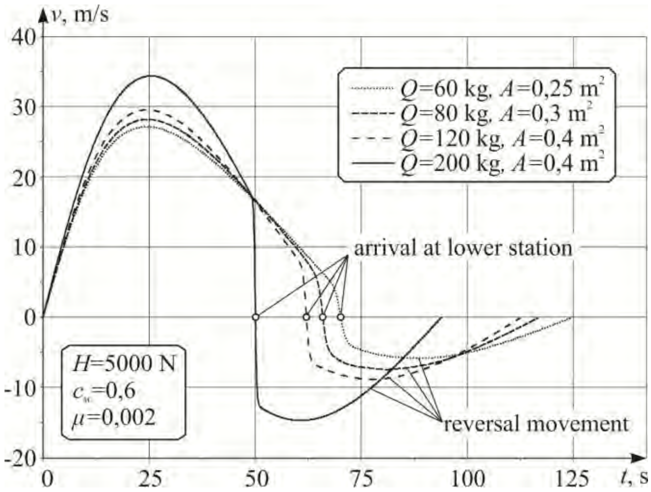

***Fig. 8** Diagram of velocity for different values of person's mass*

Diagram shown on figure 8 represents the change of velocity as function of traveling time for tensile rope force of 5000 N and different values of person's mass. It is notable that heavier persons are achieving greater maximal velocity.

4 CONCLUSION

As already mentioned, it is notable that increase of tension rope force increases reach, but reduces maximal achieved velocity. That means that in case of lower tensioning forces it is often need to foresee devices to "pull out" person from section, while in case of greater tension force there is need for stopping devices.

On the other hand, for a given tensile force, heavier passengers are achieving higher maximal velocity. Considering that it is an extreme sport, it would be desirable to achieve velocity as high as possible. This could be achieved e.g. by adding weights to lighter passengers.

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Contact address:
Tanasije Jojić
University of Novi Sad
Faculty of Technical Sciences
21000 Novi Sad
Trg Dositeja Obradovića 6
E-mail: tanasijejojic@uns.ac.rs

UNIVERSITY OF NIS FACULTY OF MECHANICAL ENGINEERING

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A CONTRIBUTION TO THE SELECTION OF ADEQUATE MCDM TECHNIQUE: STATISTICAL COMPARISON OF THE SELECTION RESULTS OF MATERIAL HANDLING EQUIPMENT

Goran MARKOVIĆ [1]
Milomir GAŠIĆ [1]
Mile SAVKOVIĆ [1]
Nebojša ZDRAVKOVIĆ [1]
Bratislav SREDOJEVIĆ [1]
Marko POPOVIĆ [2]

[1)] University of Kragujevac, Faculty of Mechanical and Civil Engineering in Kraljevo, Serbia
[2)] University of Kragujevac, Faculty of Technical Sciences Čačak, Serbia

Abstract

Selecting an appropriate MCDM technique determines the quality of the recommended decision and can save computation time without sacrificing quality in the final rank of alternatives. In addition, according to the standard MCDM methods, the most common issues are in topics of standardizing criteria and obtaining criteria weights, the possibility to work with massive data (a large number of criteria and alternatives) as well as the ranking and selecting the most desirable alternative. The purpose of this paper was to give a systematic review of the literature on MCDM techniques and make adequate support for decision-making in the selection procedure in the domain of logistics systems. Kendall's tau-b and Spearman's rho test has been selected to evaluate the similarity of the final ranks produced by different decision-ranking techniques. The results can guide in the formation of a comprehensive tool for solving a wide range of real and practical engineering problems.

***Keywords**: decision-making, material handling, criteria, Kendall's tau-b, Spearman's rho*

1INTRODUCTION

The material handling process incorporates a wide range of equipment and systems that support logistics and make the logistics system work.

The determination of the proper material handling system is important for reduced costs, increased profits and efficiency of the labor force. It is observed that there are about 50 different types of material handling equipment (MHE) and they are characterized by about 30 different attributes [1]. For that reason, MCDM methods are the most common approach applied for the selection of MHE. Decision-makers, in great number of such real problems, must meet one or more goals as well as the numerous conflict criteria. Selecting an appropriate MCDM technique determines the quality of the recommended decision and saves computation time without sacrificing quality in the final rank of alternatives. Also, different decision-ranking methods may rank specific alternatives in different orders, and different decision-ranking methods have different levels of computational intensity.

This paper reviews the literature on MCDM techniques and the most common issues present in topics of standardizing criteria, obtaining criteria weights, the possibility to work with massive data (a large number of criteria and alternatives) as well as the final ranking and selecting the most desirable alternative. The results of this study statistically compare the performances of commonly used MCDM techniques and newly developed approach. The statistical significances of the differences between the obtained ranks are calculated using Spearman's rho and Kendall's tau-b test. This research provides efforts to create an effective decision-making process through emphasizes the importance of comparing different techniques, but there is no recommendation as to whether one technique is better than another.

1.1. Survey of related works

In the available literature do not many existing works that evaluating and comparing the performance of MCDM methods. Studies [2] and [3] give a systematic reviews of comparing the MCDM techniques. This reviews categorized and evaluated popular MCDM methods (SAW (Simple Additive Weighting**)**, ELECTRE (ELimination Et Choix Traduisant la REalité), TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution), AHP (Analytic Hierarchy Process), VIKOR (Vlse Kriterijumska Optimizacija Kompromisno Resenje) and PROMETHEE (The Preference Ranking Organization *METHod*for Enrichment of Evaluations)) in the fields of transportation and logistics, manufacturing, economy, energy and education. A significant part of multi-criteria methods belongs to outranking methods because of their adaptability to real problems [4]. In the existing literature [5, 6], there are numerous examples where the PROMETHEE methods and their modifications are used in the selection of final decisions in solving various multicriteria tasks.

When evaluating a decision-making problem, it is necessary to take into account a large number of criteria/sub-criteria and determine their relative weights. Therefore, in order to make an accurate and flexible decision, some studies developed solutions for considering the interaction among criteria in the MCDM problems [7,8,9]. Criterion reduction is a useful method to extract useful knowledge from large amounts of information [10,11]. Authors give an effective decision process method which is proposed to address the challenge in the MCDM problem because of a large number of criteria.

This methods are based on the criteria reduction, tolerance relation, and prospect theory. On the other side, authors [12] identify plausible interpretations of criteria weights and their roles in different MCDM models. The true meaning of criteria weights is important for MCDM models and many different approaches were proposed for assessing criteria weights [13,14,15].

The multidimensionality mentioned above and a large number of different criteria present in such problems indicate that there are many different approaches and models for formulating and solving them. The most commonly used approach for this purpose is the application of an analytically hierarchical procedure - AHP [16,17]. For the purpose of procuring new equipment, the AHP technique is used for determining the relative weights of the criteria and the ranking of alternatives is performed using the higher-order PROMETHEE method [18]. These are works in the field of so-called combined or hybrid methods (based on the combined application of different decision-making methods ELECTRE, TOPSIS etc.) that address the choice of equipment that satisfies the decision maker [19, 20]. In recent years, problems related to group decision-making, decision-makers subjectivity, and the use of qualitative expressions for alternative values by individual criteria have been shown by numerous extended methods based on generalized fuzzy numbers, in the case of equipment selection [21, 22, 23] or equipment features [24, 25, 26]. Combining the methods for determining the relative importance of criteria and alternatives ranking methods, the optimal decision is made about certain multicriteria problems regardless of the nature of parameters describing it. Further review of the literature shows that part of the research in this area also focuses on the development of expert systems to support the decision on the selection of adequate equipment [27, 28].

In this paper, we selected and analyzed a few common ranking methods – SAW, TOPSIS, PROMETHEE and VIKOR and developed MODIPROM approach [29] and statistically investigated their similarities, differences, and performances in producing final ranks in the selection of appropriate material handling the equipment. Further analysis of the ranking effects obtained by different MCDM techniques determines the influences of a number of criteria, alternatives, final ranking methods on results similarities and also shows opportunities newly developed approach.

2 MCDM METHODS – THE BASIC CONCEPTS

2.1. Simple Additive Weighting (SAW) method

The basic concept of the SAW method is to search for the weighted sums obtained from the performance ratings of each alternative on all criteria. SAW method requires a process of normalizing the decision matrix to a scale that can be compared with all ratings of existing alternatives. For benefit and cost attributes, normalized performance alternatives are determined using the Eq. (1) and Eq. (2):

$$r_{ij} = \frac{x_{ij}}{x_j^{\max}} \tag{1}$$

$$r_{ij} = 1 - \frac{x_{ij}}{x_j^{\max}} \tag{2}$$

where are: x_{ij} - the current value (performance/rating) of the *i-th* alternative with respect to the *j-th* criterion and x_j^{max}- the maximum value (maximum performance) of all alternatives with respect to the C_j criterion. After that, the best alternative is determined by applying Eq. (3):

$$A^* = \max_i \sum_{i=1}^{m} r_{ij}\omega_j \tag{3}$$

where ω_{ij} is theweights of all criteria.

2.2. Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS)

The principle of TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) is the chosen alternative must have the closest distance from the ideal ideal solution and furthest from the ideal ideal solution from a geometric point of view using the Euclidean distance to determine the relative proximity of an alternative with the optimal solution. According to TOPSIS, we computing the elements of the normalised decision matrix $\left(r_{ji}\right)$:

$$r_{ji} = \frac{x_{ji}}{\sqrt{\sum_{j=1}^{N} x_{ji}^2}}, j = 1,2,...,N; i = 1,2,...,k \tag{4}$$

where x_{ji} is value of alternative j with respect to attribute i. The weighted normalized decision matrix can be calculated by multiplying each row of the normalised decision matrix with its associated attribute weight, because all attributes do not have same importance:

$$v_{ji} = \omega_i r_{ji}, j = 1,2,...,N; i = 1,2,...,k \tag{5}$$

where ω_i is weight of i –th attribute.

After the weighting procedure step, positive-ideal solution A^* and negative-ideal solution A^- must be defined. Determination of the positive-ideal solution can be made by taking the largest elements for each benefit attribute, and the smallest element for each cost attribute. The negative-ideal solution is the opposite formation of the positive solution.

$$A^* = \left\{v_1^*, v_2^*, ..., v_i^*, ..., v_k^*\right\}$$

$$v_i^* = \left\{\max_j v_{ji}^*, i \in J_1; \min_j v_{ji}^*, i \in J_2\right\} \tag{6}$$

$$A^- = \left\{v_1^-, v_2^-, ..., v_i^-, ..., v_k^-\right\}$$

$$v_i^- = \left\{\max_j v_{ji}^-, i \in J_1; \min_j v_{ji}^-, i \in J_2\right\} \tag{7}$$

J_1 is the set of benefit attribute and J_2 is the set of cost attributes.

Finally, distance between alternatives can be measured by the Euclidean distance. Separation of each alternative from the positive-ideal and negativ-ideal solution is given by:

$$S_j^* = \sqrt{\sum_{i=1}^{k}\left(v_{ji} - v_i^*\right)^2}, j = 1,2,...,N \quad (8)$$

$$S_j^- = \sqrt{\sum_{i=1}^{k}\left(v_{ji} - v_i^-\right)^2}, j = 1,2,...,N \quad (9)$$

Relative closeness of A_j with respect to A^* is defined as

$$C_j^* = \frac{S_j^-}{S_j^* + S_j^-}, 0 < C_j^* < 1; j = 1,2,...,N \quad (10)$$

where C^*_j is close to 1, the alternative is regarded as ideal, or when it is close to 0 the alternative is regarded as non-ideal.

2.3. Preference Ranking Organization Method for Enrichment of Evaluations (PROMETHEE)

Promethee is one method of determining the order or priority in MCDM. The task of optimization is to enable selection of the best variant (best solution) from a series of variants, i.e. in its mathematical form optimization is reduced to maximization of the criterion function $Max\{f_1(x),..., f_n(x)\}$ in the given set $x \in A\{a_1,...,a_m\}$. The values f_{ij} are known for each criterion f_j for each possible alternative A_i

$$f_{ij} = f_j(a_{ij})\ \forall(i,j);\ i = 1,2,\ldots,m;\ j = 1,2,\ldots,n \quad (11)$$

The procedure of ranking the m number of alternatives $A=\{a_1,...,a_i,...a_m\}$ covers generalization of the concept of the n number of criteria $f=\{f_1,...,f_k,..f_n\}$, establishing ranking relations and a comparative analysis of results. Let $f_j(a)$ be the value of the criterion f_j for the alternative a. After the creation of the initial matrix, one preference value $P_j(a,b)$ is assigned to each criterion which makes the basis for comparison of two alternatives, and it expresses the intensity of preference of the alternative a in relation to the alternative b. On the basis of preference functions, which are infinite, the type of generalized criterion function whose value is between 0 and 1 is chosen and, in a general case, that value is:

$$P_j(a,b) = \begin{cases} 0, \text{if } f(a) \le f(b) \\ P_j\left[f(a) - f(b)\right] = P_j\left[d(a,b)\right] \end{cases} \quad (12)$$

Six types of generalized criterion functions for expressing preferences of the decision maker regarding concrete criteria for the problem is the main characteristic of this family of methods. Each criterion is assigned a certain weight $\omega_j, j=1,...,k$ as a measure of relative importance of the criterion, so that $\sum_{j=1}^{k}\omega_j = 1,\ 0<\omega_j < 1$.

The multicriteria preference index is determined in accordance with the expression:

$$\Pi(a,b) = \sum_{j=1}^{k}\omega_j p_i(a,b) \quad (13)$$

The index represents the measure of preference of the alternative a in relation to the alternative b and the closer it is to one, the preference is bigger. It takes into account all criteria at the same time. The positive, negative and net outranking flows of action are now defined for each alternative. The net outranking flow of the alternative a represents the difference:

$$\Phi(a) = \Phi^+(a) - \Phi^-(a) \quad (14)$$

where the negative outranking flow ($\Phi^-(a)$) and the positive outranking flow ($\Phi^+(a)$) are respectively:

$$\Phi^-(a) = \sum_{\forall b\in A}\Pi(b,a) \quad (15)$$

$$\Phi^+(a) = \sum_{\forall b\in A}\Pi(a,b) \quad (16)$$

In accordance with PROMETHEE I, it is established that the higher the output flow, the more other alternatives are dominated by the alternative a, and the lower the input flow, the smaller number of other alternatives dominate over a. In other words:

- if ($\Phi^-(a) \ge \Phi^+(b)$ and $\Phi^+(a) \le \Phi^+(b)$, it is said that a prefers b.

The equality Φ^- and Φ^+ point to indifference during comparison of two alternatives. The alternatives a and b are incomparable if:

- $\Phi^-(a) > \Phi^-(b)$ and $\Phi^+(a) > \Phi^+(b)$ or
  $\Phi^-(a) < \Phi^-(b)$ and $\Phi^+(a) < \Phi^+(b)$

In PROMETHEE II, the net outranking flow indicates the priority of each alternative in relation to the others and gives the complete ranking of alternatives. Thus, the value of difference between flows is used for ranking all alternatives in such a way that a better alternative corresponds to a higher value:

- if $\Phi(a) > \Phi(b)$, it is said that a prefers b
- if $\Phi(a) = \Phi(b)$, it is said that a is indifferent in relation to b

The PROMETHEE III method performs ranking by assigning each alternative a the interval $[x_a, y_a]$ on the basis of which the complete ranking for each pair of alternatives (a,b) is determined using the following definitions:

- if $x_a > x_b$, it is said that a prefers b (has a higher rank),
- if $x_a \le y_b$ i $x_b \le y_a$, it is said that a is indifferent in relation to b,where are:

$$x_a = \Phi(a) - \alpha\sigma_a$$

$$y_a = \underline{\Phi}(a) + \alpha\sigma_a$$

$$\underline{\Phi}(a) = \frac{1}{m}\sum_{b\in A}(\Pi(a,b) - \Pi(b,a)) = \frac{1}{m}\Phi(a)$$

$$\sigma_a = \sqrt{\frac{1}{m}\sum_{b\in A}(\Pi(a,b) - \Pi(b,a) - \underline{\Phi}(a))^2}$$

$$\alpha > 0$$

2.4. The MODIPROM method (MODIfied PROmethee Method)

The developed MODIPROM method (MODIfied PROmethee Method)[29] is based on the improvement of a group of methods for multicriteria ranking, as follows:

- change of the existing generalized criteria and introduction of the new ones,
- procedure of selection of generalized criteria within one criterion function,
- analysis of effects of change of weight coefficients, and
- transformation of the mean values of the outranking flow for the purpose of solving complex criterion functions.

Changes of generalized criteria refer to retaining generalized criteria I (Usual criterion), II (U-shape criterion), IV(Level criterion) and VI (Gaussian criterion). Criterion III (V-shape criterion) and V (V-shape with indifference criterion) are replaced with the linear criterion whose parameters are calculated through linear regression. The square and cube criteria whose parameters are calculated by regression analysis are introduced. The influence of experience and subjective evaluation of the decision maker in the selection of generalized criteria is reduced to minimum, in other words, the selection performed on the basis of the methods of the least squares so that the generalized criterion is chosen in which the sum of squares of deviations of experimental points from the theoretical curve of the generalized criterion is least.

2.5. VIKOR method (VIse Kriterijumska Optimizacija Kompromisno Resenje)

This method focuses on ranking and selecting from a set of alternatives and determines compromise solution for a problem with conflicting criteria. The VIKOR method determines the best f_j^* and the worst f_j^- values of all criterion functions *j=1, 2,...,n* (if the *j-th* function represent a benefit: $f_j^* = \max_j f_{ij}, f_j^- = \min_j f_{ij}$). In the next step, the values S_i and R_i are computed by Eq.(17):

$$S_i = \sum_{j=1}^{n} \omega_j (f_j^* - f_{ij}) / (f_j^* - f_j^-)$$
$$R_i = \max_j \omega_j (f_j^* - f_{ij}) / (f_j^* - f_{ij}) \quad (17)$$

where w_j are the weights of criteria. The values Q_i, *i=1,2,...,m* are computed by relation:

$$Q_i = v(S_i - S^*) / (S^- - S^*) + (1-v) / (R_i - R^*) / (R^- - R^*) \quad (18)$$

where are:

$$S^* = \min_i S_i,\ S^- = \max_i S_i,$$
$$R^* = \min_i R_i,\ R^- = \max_i R_i.$$

and v is weight of the strategy of the majority of criteria.
Sorrting by the values *S, R* and *Q* in decreasing order is obtained a final ranking of the alternatives. Proposing as a compomise solution the alternative *A'*, which is ranked the best by the measure *Q* (minimum) if the following two condition are satisfied:

- Acceptable advantage: $Q(A'') - Q(A') \geq DQ$, where A'' is the alternative with second position in the ranking list by *Q*: *DQ=1/(m-1)*, *m* is the number of alternatives.
- Acceptable stability in decision making: Alternative *A'* must also be the best ranked by *S* or/and *R*. This compromise solution is stable within a decision making process (which could be: when ν>0.5 is needed-*voting by majority rule;* ν≈0.5- *by concesus*; ν<0.5 – *with veto*).

If one of the condition is not satisfied, than a set of compromise solution is proposed:

- Alternatives *A'* and *A''* if only condition C2 is not satisifed or
- Alternatives *A', A'',..., $A^{(M)}$* if condition C1 is not satisfied, $A^{(M)}$ is defined by the relation $Q(A^{(M)}) - Q(A') < DQ$ for the maximum M (the positions of these alternatives are *in closeness*)

The obtained compromise solution could be accepted by the decision makers because it provides a maximum "*group utility*" (represented by min *S*) of the "*majority*", and a minimum of the "*individual regret*" (represented by min *R*) of the "*opponent*". The compromise solutions could be the basis for negotiations, involving the decision maker's preference by criteria weights.

3 STATISTICAL COMPARISON OF RANKING METHODS

Kendall's tau-b and Spearman's rho test were selected to analyze the produced ranks through different decision-ranking methods in terms of their pairwise correlations. These two non-parametric tests are used to measure the ordinal association between the two measured quantities (the final ranks compare among the methods) and to test for associations in hypothesis testing. The null hypothesis (H_0) is that there is no association between the variables under study or that there is no correlation. To prove something using statistics, you should assume the opposite, that there is no correlation between your data sets. The p (or probability) value obtained from the calculation is a measure of how likely or probable it is that any observed correlation is due to chance. P-values range between 0 (0%) and 1 (100%). A p-value close to 1 suggests no correlation other than due to chance and that your null hypothesis assumption is correct. If your p-value is close to 0, the observed correlation is unlikely to be due to chance and there is a very high probability that the null hypothesis is wrong. In this case, you must accept the alternative (H_1) hypothesis that there is a correlation between your data sets.

3.1. Kendall's tau-b test

Kendall's tau-b test coefficients indicate the concordant and discordant association between the ranks of two compared groups of ranks. Kendall's tau-b coefficient is calculated using Eq. (19) as follows [2]:

$$\tau_B = \frac{n_C - n_D}{\sqrt{(n_0 - n_1)(n_0 - n_2)}} \quad (19)$$

where are:

$n_0 = n(n-1)/2$, $n_1 = \sum_i t_i(t_i - 1)/2$, $n_2 = \sum_j u_j(u_j - 1)/2$, and n_C is the number of concordant pairs; n_D is the number of discordant pairs; t_i is the number of tied values in the *i-th* group of ties for the first quantity and u_j is the number of tied values in the *j-th* group of ties for the second quantity. This formulation yields τ_B between −1 and + 1. The value

of −1 stands for 100% negative association, and the value of + 1 stands for 100% positive associations.
The value of zero stands for the absence of any association. The main advantages of using Kendall's tau-b test are as follows:

- The distribution of Kendall's tau-b has better statistical properties.
- The interpretation of Kendall's tau-b in terms of the probabilities of observing the agreeable (concordant) and non-agreeable (discordant) pairs is very direct.
- In most of the situations, the interpretations of Kendall's tau-b and Spearman's rank correlation coefficient are very similar and thus invariably lead to the same inferences.

3.2. Spearman's rho test

Spearman's rank correlation test, which is a special form of correlation test, is used when the actual values of paired data are substituted with the ranks, which the values occupy in the respective samples [2]. Spearman's rho usually has larger values than Kendall's tau and calculations are based on deviations and much more sensitive to error and discrepancies in data.
The Spearman's rank correlation coefficient value (Eq.(20)) is a statistical measure of the strength of a link or relationship between two sets of data.

$$r_s = 1 - \left[\frac{6 \cdot \sum_{j=1}^{K} (d_j)^2}{K(K^2 - 1)} \right] \quad (20)$$

The answer will always be between 1.0 (a perfect positive correlation) and -1.0 (a perfect negative correlation). An r_s of 0 indicates no association between ranks (Fig.1).

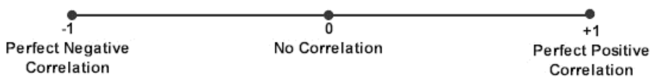

Fig.1 *The association between ranks*

We can describe the strength of the correlation using the following guide for the value of r_s (Table 1).

Table 1 The strength of a correlation

The strength of a correlation	
Value of coefficient r_s (positive or negative)	**Meaning**
0.00 to 0.19	A very weak correlation
0.20 to 0.39	A weak correlation
0.40 to 0.69	A moderate correlation
0.70 to 0.89	A strong correlation
0.90 to 1.00	A very strong correlation

A guide to interpreting a p-value is shown on Fig.2. So you must accept the alternative hypothesis (that there is a strong positive correlation between your data sets) and reject the null hypothesis that there is no correlation. This correlation does not imply causation. One variable may not cause the other.

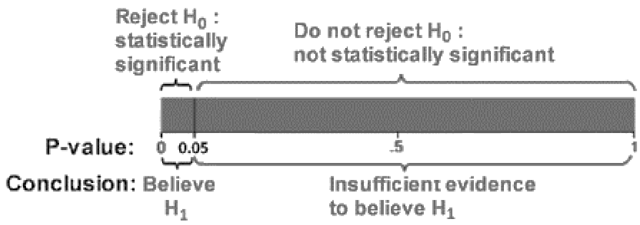

Fig.2 *A guide to interpreting a p-value*

4 NUMERICAL EXAMPLE AND ANALYSIS

In this section, the numerical example of purchasing a forklift for the one warehouse facility is analyzed. It is an MCDM problem and for ranking a set of forklift alternatives that satisfy in advance required parameters, the initial set of 9 characteristics was observed (Table 2).

Table 2 *A initial set of selection criteria and alternatives*

Model	**Capacity (kg)**	**Max. lift height (mm)**	**Travel speed with the load (km/h)**	**Lift speed with the load (m/s)**	**Turning radius (mm)**	**Level of noise (dB)**	**Engine power (kW)**	**Wheel-base (mm)**	**Total width (mm)**
7FBEST15	1500	3310	12	0.3	1450	62.4	7.5	1200	990
2ET2500	1300	3000	16	0.48	1440	66	11.5	1249	1060
2ETC3000	1600	3000	16	0.49	1548	66	11.5	1357	1060
J30XNT	1361	3032	15.7	0.39	1481	69	4.8	1290	1050
J35XNT	1588	3032	15.7	0.36	1577	69	4.8	1386	1050
TX30N	1350	3300	14.5	0.34	1525	61	10.7	1300	1105
TX35N	1600	3300	14.5	0.31	1525	61	10.7	1300	1105
ERP15VC	1500	3320	12	0.3	1452	59	6	1222	996
ERP15VT	1500	3320	16	0.43	1476	65	12	1290	1050
ERP16VT	1600	3320	16	0.43	1476	65	12	1290	1050

In order to analyze and to compare the results of ranking are developed the program tools in the environment of Microsoft Excel. The fourth decision matrices were developed (with 5 alternatives and 5 criteria (5A-5C); 7 alternatives and 7 criteria (7A-7C); 10 alternatives and 9 criteria (10A-9C) and 5 alternatives and 7 criteria (5A-7C) in order to investigate the role of changing of criteria number.

The fourth standard MCDM methods and recently developed approach were applied to each decision matrix. The final, sorted ranks were statistically analyzed by Kendall's tau-b and Spearman's rho test using a specific macro written in Excel.

4.1. Numerical results and discussion

Table 3 gives a statistical results of the Spearman's rho and Kendall's tau-b test for decision matrix with 10 alternatives and 9 criteria. The results obtained for α-level = 0.05 shows similarity of performances between two statistical test. The Sig (2-tailed) p-value tells us if correlation was significant at a chosen alpha level. If p-value is small, then the correlation is significant.For the purpose of investigating the correlation strength between ranks obtained with analyzed methods, Kendall's tau-b correlation coefficients have been selected as supplementary data sets for further evaluation.

Fig. 3-7 shows the statistical results of the correlation significance percentages among different ranking methods applied on decion matrices with 5 alternatives and 5 criteria; 7 alternatives and 7 criteria; 10 alternatives and 9 criteria.

Table 3 Correlation coefficient obtained by different ranking methods for decision matrix with 10 alternatives and 9 criteria

	SAW	TOPSIS	PROMETHEE	MODIPROM	VIKOR
Sperman's rho test					
SAW	1.000	0.050	-0.15	-0.016	0.116
TOPSIS	0.050	1.000	-0.116	-0.050	0.450
PROMETHEE	-0.150	-0.116	1.000	0.666	0.050
MODIPROM	-0.016	-0.050	0.666	1.000	-0.016
VIKOR	0.116	0.450	0.050	-0.016	1.000
Kendall's tau-b test					
SAW	1.000	0.055	-0.111	0.000	0.055
TOPSIS	0.055	1.000	-0.055	-0.055	0.333
PROMETHEE	-0.111	-0.055	1.000	0.444	-0.055
MODIPROM	0.000	-0.055	0.444	1.000	0.055
VIKOR	0.055	0.333	-0.055	0.055	1.000

The results show that SAW had the highest significant correlation percentages with the TOPSIS; MODIPROM had the highest significant correlation percentages with PROMETHEE; PROMETHEE had the highest significant correlation percentages with MODIPROM and partially with VIKOR. SAW and TOPSIS had the lowest significant correlation percentages with VIKOR.

Fig. 8-12 ilustrated the comparasion of results of ranking methods applied on decision matrix with an equal number of alternatives as the number of criteria increased (5 alternatives and 5 criteria and 5 alternatives and 7 criteria). The statistically significant correlation percentage is mostly constant for SAW but in the case of VIKOR methods increases. It is evident that in all cases the results of the ranking obtainedwith new approach MODIROM are statistically similar to theresults obtained by other traditional approaches.For a better analysis of the influence of changing the number of criteria, it is necessary to applied MCDM methods on decision matrices different sizes.

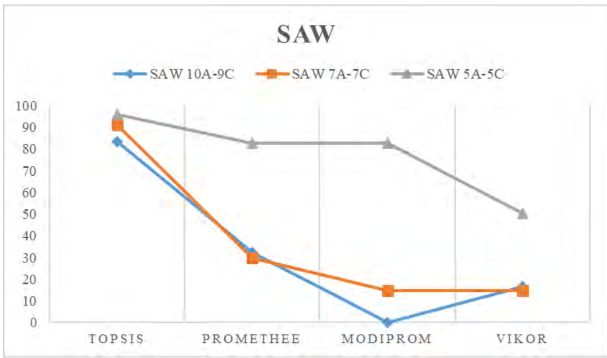

Fig.3 *Multiple comparasion of statistical results of SAW versus different methods*

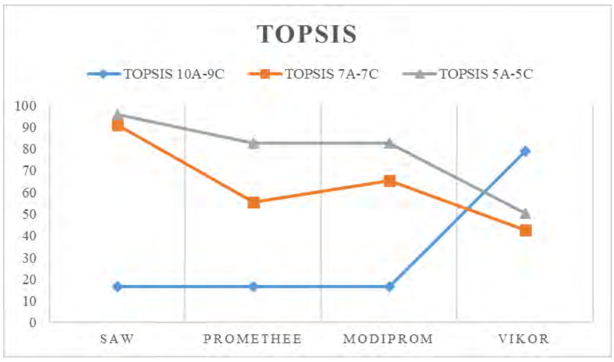

Fig.4 *Multiple comparasion of statistical results of TOPSIS versus different methods*

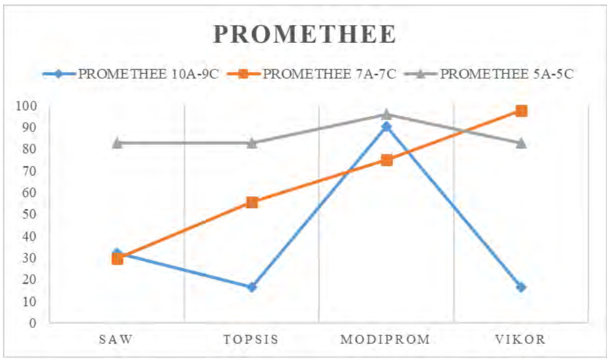

Fig.5 *Multiple comparasion of statistical results of PROMETHEE versus different methods*

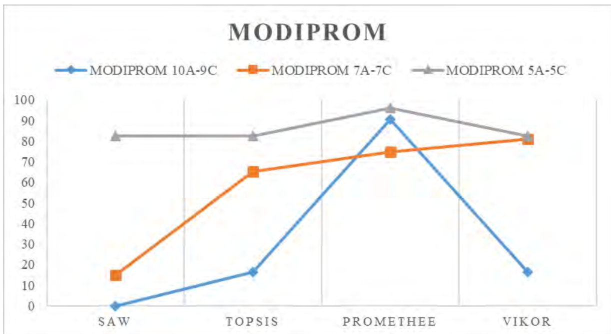

Fig.6 *Multiple comparasion of statistical results of MODIPROM versus different methods*

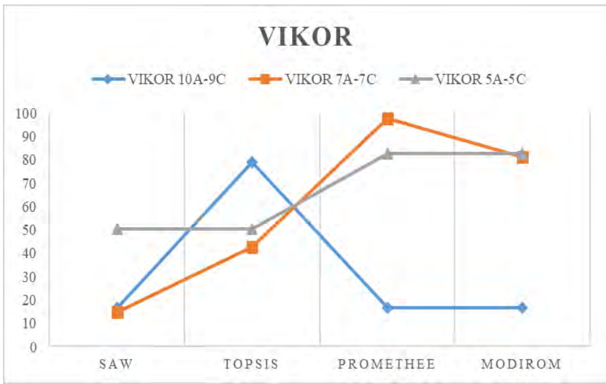

Fig.7 *Multiple comparasion of statistical results of VIKOR versus different methods*

Fig.8 *Comparasion of statistical results of SAW versus different methods applied on decision matrices with 5A-5C and 5A-7C*

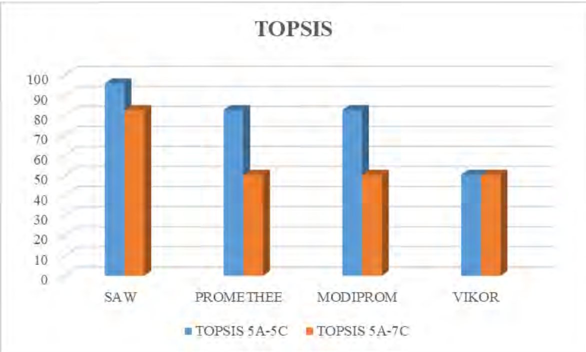

Fig.9 *Comparasion of statistical results of TOPSIS versus different methods applied on decision matrices with 5A-5C and 5A-7C*

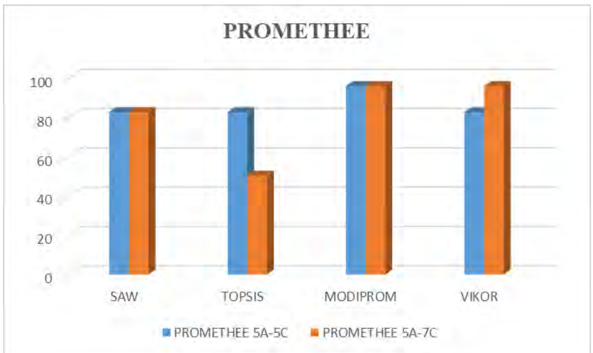

Fig.10 *Comparasion of statistical results of PROMETHEE versus different methods applied on decision matrices with 5A-5C and 5A-7C*

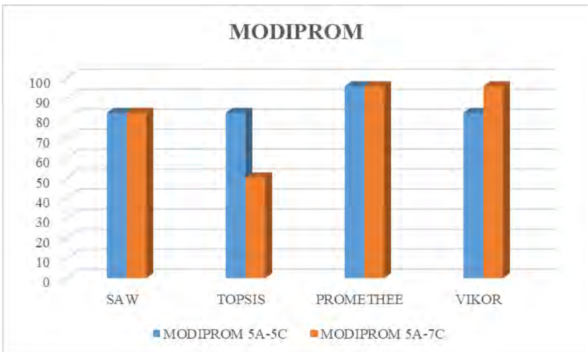

Fig.11 *Comparasion of statistical results of MODIPROM versus different methods applied on decision matrices with 5A-5C and 5A-7C*

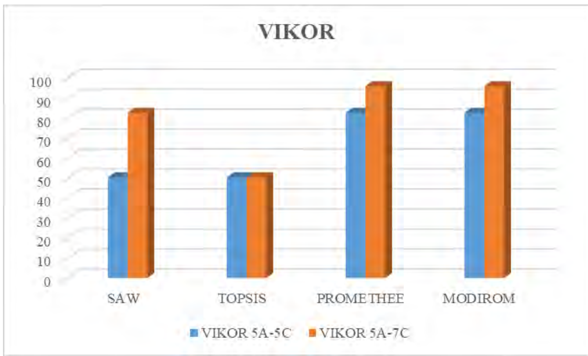

Fig.12 *Comparasion of statistical results of VIKOR versus different methods applied on decision matrices with 5A-5C and 5A-7C*

6 CONCLUSION

Statistical analysis of the different decision matrices indicates that SAW and TOPSIS as well as PROMETHEE and MODIPROM have similar performances and produced almost identical performances. Also, the graphical presentation of the results indicates that by increasing the size of the decision matrix the p-value or percentage of significant correlation among the ranks of pairwise decreases. On the other side, with increasing the number of criteria for the same number of alternatives statistical significant correlation percentage is mostly constant for SAW, PROMETHEE and MODIPROM, but a decreases for TOPSIS. This research provides efforts to create an effective decision-making process and emphasizes the importance of comparing different techniques, but there is no recommendation as to whether one technique is better than another. Also, the results of this study statistically compares the performances of commonly used and classic MCDM techniques and proposed a new approach. The results can guide in the formation of a comprehensive tool for solving a wide range of real and practical engineering problems. Definition of new cases i.e. comparasions of results obtained under fuzzy enviroment (in most real situation criteria are not deterministic) or obtained by new hybrid models are direction for further analysis. Also, it is recommended to investigate the magnitude of the correlation coefficients among the ranks by different techniques applied on the same decison matrix with changing of relative weights of criteria and their number.

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Contact address:
Goran Marković
University of Kragujevac
Faculty of Mechanical and Civil Engineering in Kraljevo
36000Kraljevo, Dositejeva 19
E-mail: markovic.g@mfkv.kg.ac.rs

UNIVERSITY OF NIS FACULTY OF MECHANICAL ENGINEERING

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DEVELOPMENT AND DESIGN OF THE SPECIAL VEHICLE FOR THE TRANSPORTATION OF HEAVY WEIGHT CONSTRUCTION MACHINES

Mile SAVKOVIĆ[1]
Goran MARKOVIĆ[1]
Nebojša ZDRAVKOVIĆ[1]
Boris MILOVANOVIĆ[1]
Goran PAVLOVIĆ[2]
Milomir GAŠIĆ[1]
Bratislav SREDOJEVIĆ[1]

[1)]University of Kragujevac, Faculty of Mechanical and Civil Engineering in Kraljevo, Dositejeva 19, Kraljevo
[2)]R&D Center Alfatec Ltd Bul. Nikole Tesle 63/5, 18000 Niš, Serbia

Abstract

A big issue in the construction industry is the transportation of the heavyweight machines from urban areas or production facilities to the construction site and back. Nowadays, low loader trailers are utilized for this kind of transport. They are towed by trucks, where the transport speed is significantly decreased and the ability to reach the construction site is also reduced. To overcome this difficulty, it is necessary to eliminate the low loader trailers from the transportation equipment and use special automotive vehicles. This paper presents the design of one of them. The structure of a standard vehicle with 32-tone gross weight is upgraded to carry and transport heavyweight construction machines. Also, the rear end is equipped with a hydraulically powered ramp for loading the machine onto the vehicle and unloading it off the vehicle.
The stress analysis of the upgraded structure was conducted by the finite element method (FEM) and the optimization was carried out. The stress analysis was done for four different case studies. The stress and the deformation results confirmed the validity of such a design solution for the transportation of heavyweight construction machines.

***Keywords**: special vehicle, buildings maschine, transportation, stress analysis*

1 INTRODUCTION

In accordance with the technological development, plants, machinery and means of transport which are used for development of the economic system have significantly evolved[1]. A large number of earth-excavating and other working machines with considerably higher capacities and performance have been developed. However, the consequence is their increased overall dimensions and masses. They also have a restricted radius of motion because their speeds of motion are reduced. Also, due to the increase in their masses, there occurs another problem, i.e. they can cause mechanical damage of roads and considerably slow down the traffic because of their low speed of motion.
For the mentioned reasons, these machines are most often transported by special machines which are called truck trailers. These vehicles have a high carrying capacity, a higher speed than the working machines themselves and a higher radius of motion. However, these machines have their own weaknesses, which, before all, refer to the necessity to provide a traction vehicle for their motion. By attaching truck trailers to the traction vehicle, the total length of the vehicle itself is increased, which restricts its motion and access to the terrain. Also, the height of the vehicle in transport is increased, which can be a problem while passing through tunnels, underpasses, etc. regardless of the type of truck trailer used.

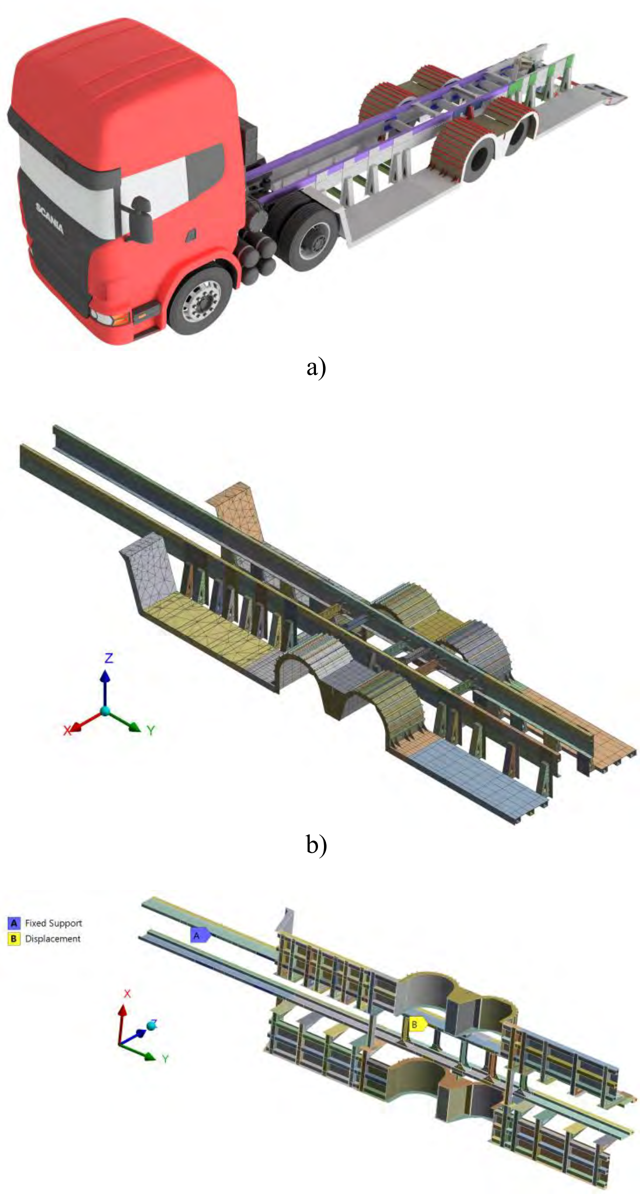
Three most common types of special vehicle for the transport of heavy-duty earth-excavating machines on our market are:

- truck trailers with a semi-trailer,
- truck trailers with a trailer and
- truck trailers with multiple trailers.

All mentioned types have common negative characteristics, i.e. great length, larger radius of rotation and large overall height.
This problem can be solved to a large extent if special vehicles for the transport of heavy loads – without a trailer are used. The structure of such a vehicle is the subject of this paper.

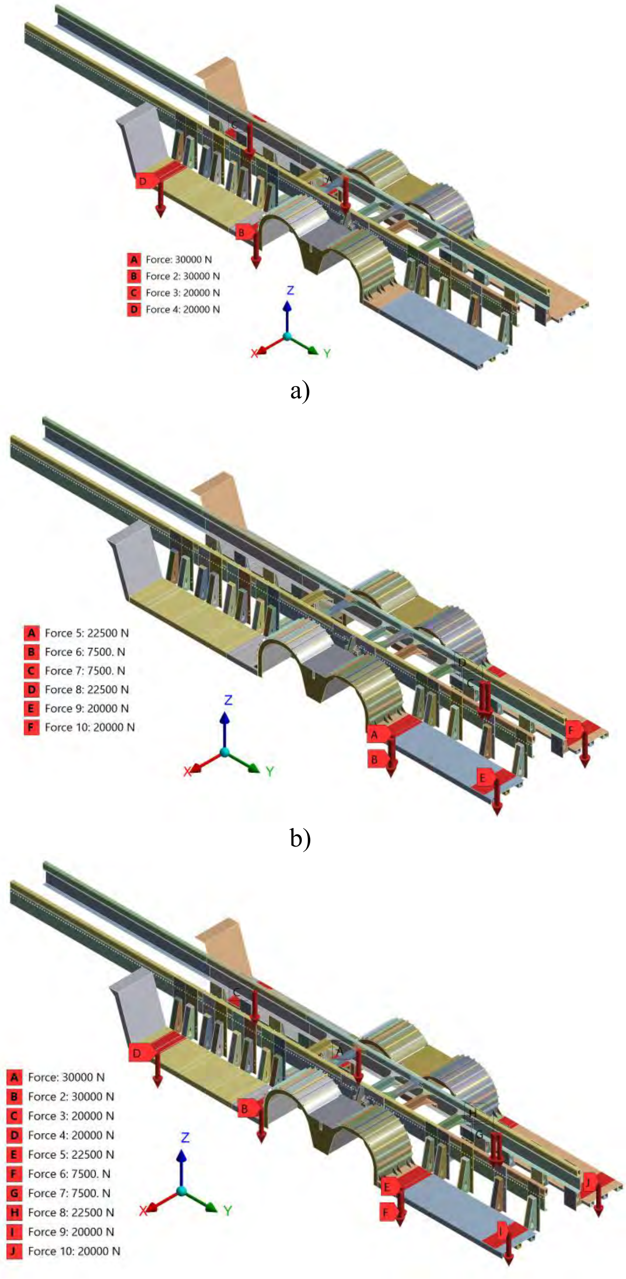
2 TECHNICAL DESCRIPTION OF THE SOLUTION

This paper presents the possibility of elimination of a low loader trailer in favour of using a special automotive vehicle for the transport of large earth-excavating machines. This vehicle is obtained by adding a superstructure to the carrying structure on the chassis of the standard vehicle, in this case vehicle Mercedes 930.20 (trademark Mercedes 3244). The superstructure is designed in such a way that, with small modifications, it can be adapted and mounted on other types of vehicles. The axle distance between the first and second axles is 3900 mm, and the axle distance between the second and third axles is 1350 mm. The base of the chassis of the vehicle is the U-shaped girder whose height is 285 mm, width 70 mm and thickness 8 mm.
The width of the chassis is 760 mm (the distance between the outer edges of the girder).



a) b) c)

Fig. 3*Model of the structure*



a) b) c)

Fig. 4*Characteristic cases of the loading of the structure*

In the analysis by the finite element method, those parts which are not of importance for the analysis (front part of the vehicle, with the cabin, drive motor, etc.) are eliminated. The influence of the eliminated part is taken through the corresponding supports.

Three characteristic positions of the vehicle which is being transported are adopted for calculation:

1. the transported vehicle is at the front part of the structure (Figure 4a),
2. the transported vehicle is at the rear part of the structure (Figure 4b),
3. the transported vehicle is both at the front and rear parts of the structure (Figure 4c).

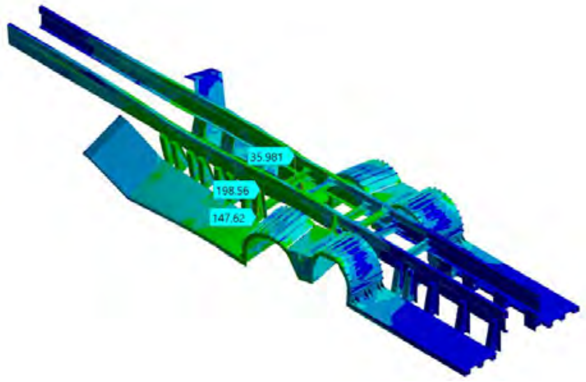
The loading of the structure depends on the mass of the vehicle as well as on the carrying structure which is mounted as the superstructure.

The permissible gross mass of the mentioned vehicle is 32 tonnes. As the mass of the vehicle with the carrying structure is about 14 tonnes, the mass of the vehicle which is being transported must not exceed 18 tonnes. This value corresponds to the mass of special vehicles of earth-excavating machinery which are being transported.

3.2 Stress and strain analysis

The values of stresses and strains for all three cases of loading are presented in Figs. 5-7.

The carrying structure is made of steel S355, whose module of elasticity is E=210 GPa; - Poisson's ratio: ν=0.30; - yield criterion: von Mises - initial yield stress: σy=355 MPa.



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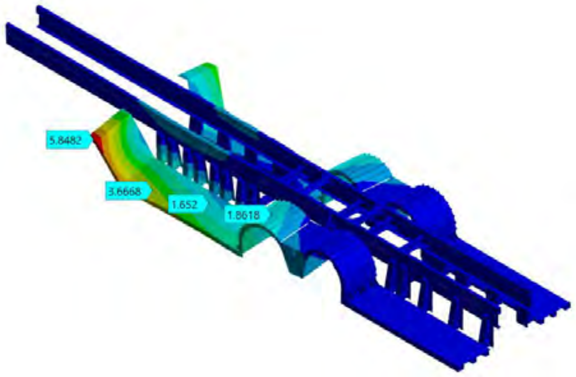
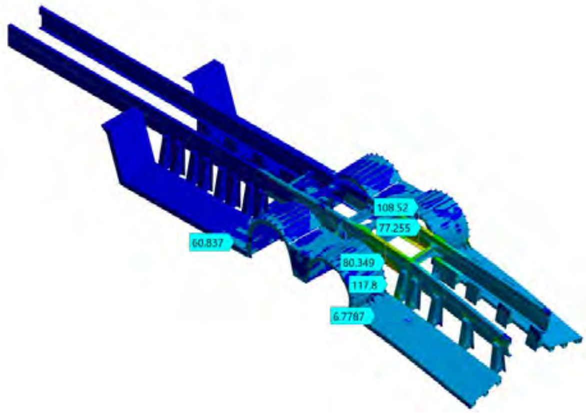
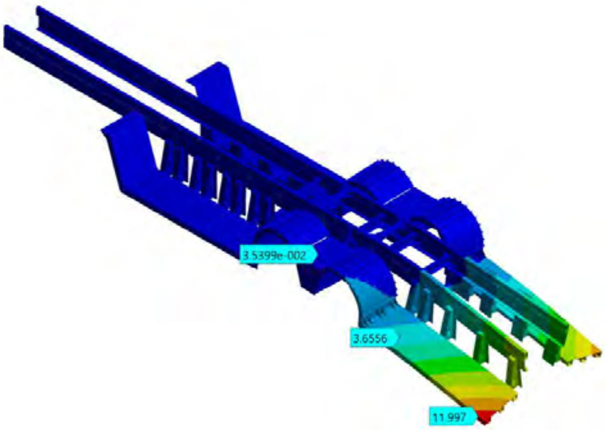


b)

Fig. 5*Values of stresses a) and strains b) for the first case of loading*

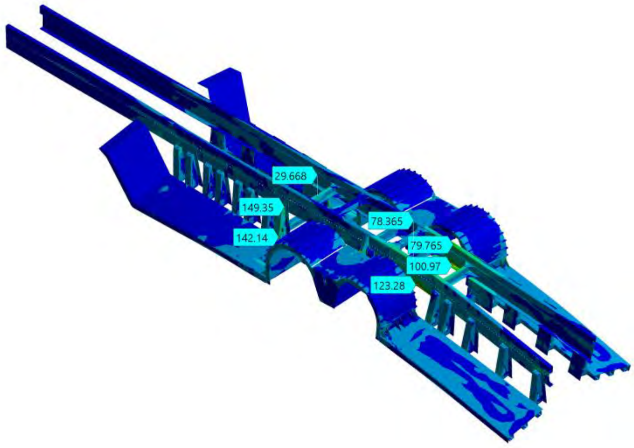


a)

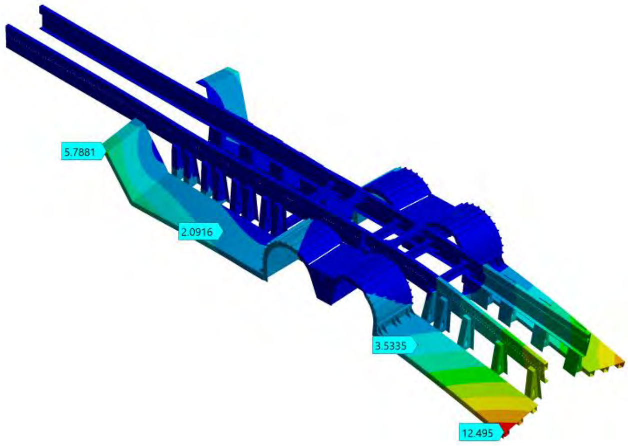


b)

Fig. 6*Values of stresses a) and strains b) for the second case of loading*



a)



b)

Fig. 7*Values of stresses a) and strains b) for the third case of loading*

In the first and second cases, the load of the structure is Q=100 kN, uniformly distributed at four points, Figure 4a and Figure 4b. In the third case, the load of the structure is Q=200 kN, uniformly distributed at eight points, Figure 4c.
In the first and second cases, the values of equivalent stress are considerably lower than the permissible ones.
In the third case, the stress values are highest near the point where the load is applied at the front part of the vehicle.
The highest values of the equivalent stress are σe=24 MPa.
It should be mentioned that the value of the real load is increased by 10%. On the basis of the analysis, it can be seen that even with these load the stresses are within the allowed limits.

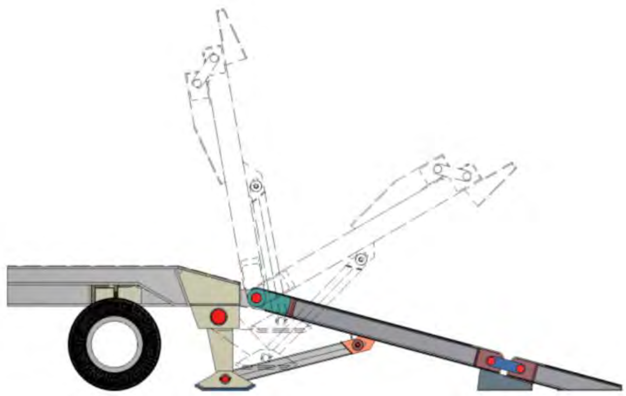


Fig. 7*Loading ramp*

At the rear part of the vehicle, a ramp for loading vehicles is installed [2], [3], [4], [5], [6], [7],and it has its hydraulic drive for lifting and lowering, which considerably facilitates the operation of loading and unloading of the vehicle. During the lowering of the ramp, the hydraulic cylinder brings the supporting leg to the lower working position. The leg is supported on the base, which relieves the rear wheel completely. By installing such a solution of loading ramp, loading and unloading are carried out without manual work of the operator, which considerably facilitates transport.

4 CONCLUSION

The analysis showed that the values of stresses and deformation for the new structural solution for the superstructure of the vehicle for transport of heavy-duty machinery are within the allowed limits, for the selected material of structure.

The new solution consists of segments which facilitate the processes of mounting on the vehicle and disassembling.

The presented solution can also be mounted on another vehicle, but the openings for connecting the plate with the main chassis of the vehicle must be adapted.

The vehicle with the mentioned superstructure can transport heavy-duty earth-excavating machinery to large distances and inaccessible locations at high speeds.

The installation of a self-loading ramp with hydraulic drive excludes the manual work of the operator, which considerably reduces the time for loading and unloading of the vehicle and facilitates the work of the operator.

ACKNOWLEDGMENT

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Contact address:
Mile Savković
University of Kragujevac
Faculty of Mechanical and Civil Engineering
36000 Kraljevo
Dositejeva19
E-mail: savkovic.m@mfkv.kg.ac.rs

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TRANSPORT COMFORT DATA CLUSTERING

Zeljko JOVANOVIC [1]
Dragan JANKOVIC [2]

[1)] *Department of Computer Engineering, Faculty of Technical Sciences Cacak, University of Kragujevac*
[2)] *Department of Computer Science, Faculty of Electronic Engineering, University of Nis*

Abstract

During the transport, large amount of data could be collected about transport comfort but it is very hard to extract valid information about location comfort. Data collected from different traffic participants in various situations need to be organized and grouped by some criteria so they could be suitable for better analysis. Depending on a driver, vehicle, road or a current transport situation, at the same location, significantly different comfort values could be measured. That's why they need to be grouped by the vehicle location for overall location comfort information.
In this paper, transport comfort data are collected with Android mobile application. It is developed to monitor embedded accelerometer sensor installed in almost every smart phone nowadays. For collected data, clustering techniques are used to group data by the location.
As a result, one overall information per cluster location is generated based on the all collected data from application users. Location comfort information are presented on the Google maps with interactive markers.

Key words*: transport, comfort, clustering, vibration*

1 INTRODUCTION (MAIN HEADING - UPPER CASE 10 PT, ALIGN LEFT, SPACING BEFORE 24 PT, SPACING AFTER 6 PT)

Each person is limited by the amount of data they can see in a unit of time. The larger the number of data that surrounds it, the harder it is to manage. To make it easier for himself, he can group the same elements into one and view them as one new element. This will reduce the number of elements that surround it and make it easier for observe. These newly formed elements are actually sets, which can contain many smaller elements that have a common denominator that connects them. The related data are called clusters, and the process of forming them is called clustering.

In the field of transport, clustering can be of great use. Tracking transport parameters is usually very complex and involves a large number of information that needs to be processed. This is due to the fact that one transport is affected by 3 main factors: driver, vehicle and road conditions. Different drivers on the same road and with the same vehicle may have completely different driving parameters measured. Also, changing the vehicle can greatly affect the measured parameters. This is especially important with trucks as their trailers can be empty or loaded. Also, the difference is significant when traveling uphill or downhill. Road conditions can be static and dynamic. Static conditions are bumps, potholes, or other problems related to a specific road surface location. Dynamic aspects are not location-related and can happen anytime, anywhere. These are weather conditions (heavy rain, snow, ice ...) but also the impact of other drivers in the form of overtaking, braking or traffic accidents.

This paper will primarily address why clustering is used and what are the possible risks that may cause problems in its implementation. The aim of the paper is to group transport data by geographical location using clustering techniques. It will also highlight the problems of clustering over specific data in geographic space. Based on all the collected data, it is necessary to create one general information about the transport conditions at a specific location.

Paper is outlined as follows. Chapter 2 will discuss the importance and problems of data clustering. Then in Chapter 3, Android application usage for data collection used clustering is presented. In Chapter 4, the development of a web application for data clustering and a demonstration of results within a realized application is presented.

2 CLUSTERING

There are many elements in space that can be used for various purposes, but primarily for analysis. Since these elements are generally distributed and their number can be enormous, analyzing the individual elements would be very slow and complicated. To avoid this, the idea is to group these elements by some rule into a certain number of sets by affinity. We could work with such sets as new elements that represent a whole range of related elements. Such a set is called a cluster, and the creation process is called clustering. The clustering principle is illustrated by the sketch in Figure 1.

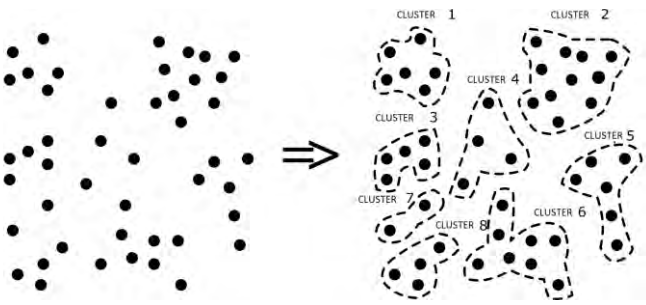

Fig. 1 *Sketch of creating a cluster over certain elements*

A cluster must contain at least 1 element in order to exist. In fact, no cluster has a predefined size, but the number of elements varies from cluster to cluster. Consequently, some clusters may be much larger than others, which can also be one of the problems. Also, cluster shapes do not have to be regular shapes, but most often they take a square and a circle in two-dimensional space or cube and ball in three-dimensional space.

The most important thing, and therefore the main problem with cluster formation, is the criteria by which they are created. One of the most used and popular methods of clustering in geographical space is the use of longitude and latitude. Since the points are compared by their geographical coordinates, then their distance from each other is crucial for clustering. Points that are close enough to each other can participate in the creation of the cluster, and so on for all points in the geographical space until each point is assigned to a particular cluster.

Each cluster is described by two parameters, namely center and diameter. The center of the cluster represents the center of gravity or arithmetic mean of all points in the cluster. Adding a new point to the cluster can move the center of the cluster, which can be a problem. Therefore, the conditions under which the cluster should change its center should be set up so that unexpected problems do not arise. The second parameter of the cluster, diameter, varies depending on the needs. The larger the diameter, the larger the number of elements will belong to it, but the number of clusters will be smaller and vice versa.

1.1. Clustering techniques

Clustering techniques[1], [2] can be divided into:

- Partitioning techniques
- Hierarchical techniques

Partitioning techniques - Division of a given set of objects into disjunct clusters so that each object belongs only to the one cluster. Fig 2. demonstrate partitioning techniques.

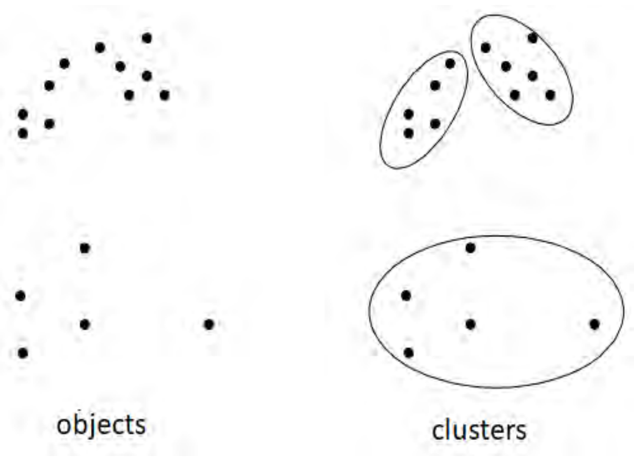

***Fig. 2**. - Partitioning techniques*

Hierarchical techniques - Divide a given set of objects into nested ones clusters that are hierarchically arranged in the form of a tree. Fig 3 demonstrate hierarchical techniques.

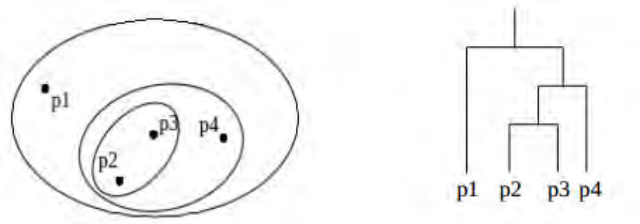

***Fig. 3** - Hierarchical techniques*

According to the problem there are additional tuning criteria for clustering technique:

- Exclusive versus non-exclusive - In non-exclusive clusters, one object can that it belongs to more clusters
- Fuzzy versus non-fuzzy - In fuzzy clusters, the object belongs to each to a cluster with some weight $0 \leq w \leq 1$
- Partial versus complete - Partial clustering covers only part of the baseline together

1.2. Cluster types

Clusters can be divided into several types:

- Well-separated clusters - Clusters where any object is closer to all objects from the same cluster than any object outside the cluster
- Center-based clusters - Clusters where any object is closer to the cluster center to which it belongs than to the center of any other cluster
- Contiguous clusters - Clusters where any object is closer to the bar to one object from that cluster than to any com an object outside the same cluster
- Density-based clusters - Clusters are "high density" regions, separated by low density regions
- Property or Conceptual - Clusters that share objects
- Described by an Objective Function

1.3. Clustering algorithms

There are several clustering algorithms used nowadays:

- K-means [3][4]
- Agglomerative hierarchical clustering [5]
- Density-based clustering [6]

K-means is the partitioning technique. Every cluster is represented with a centroid. Every object is joined to the nearest centroid. The number of clusters is input data. The initial choice of centroids is a random choice. Centroids are calculated as arithmetic mean of the objects in the cluster. It is possible that K-means create empty cluster. After clusters creation it is necessary to calculate the error. Usually it is represented with the sum of squared errors (SSE) which is calculated for every object. If it is necessary, object could change the cluster if its centroid is closer. Centroid recalculation is done after first iteration of object placement. It would be ideal to be done after every object placement but that would be very demanding. K-means algorithm is not ideal with non-round, different sizes or densities clusters.

Agglomerative hierarchical clustering algorithm generates nested hierarchical clusters as shown in Fig 3. Unlike K-means it is no necessary to know the number of clusters at the beginning. Agglomerative hierarchical technique works as follows. Initially every object is a cluster. In every step nearest clusters are joined until one cluster is created. That cluster is root of the dendrogram. There is a *devise* variation of hierarchical clustering with the opposite approach. At start, there is only one cluster which is divided into smaller once until every object becomes a cluster. Cluster join and separation is done by proximity matrix calculation with min, max or average distance calculation algorithm.

Density-based clustering (DBSCAN) algorithm as it says is organized by the density of the object in some circle radius. Object are classified as core, border or noise objects. Core object are in the cluster radius. Border objects are near the end of the radius, while noise objects are far away the cluster radius. Besides radius it is necessary to calculate minimum objects parameter (MinPts). It represents minimum number of objects which represent one cluster.

3 TRANSPORT COMFORT DATA GATHERING

Transport comfort is usually estimated by the accumulated vibration during the transport. One of the most suitable sensors for vibration monitoring is accelerometer. Nowadays it is present in almost every smart phone. It is used for better user experience with screen orientation or some other motions activity. Also, it can be used for vibrations monitoring. For transport comfort monitoring, an Android application was developed. It is based on three axes' accelerometer data calculations and GPS data monitoring. The development of the main application functionalities was presented in [7] while advanced version in [8] . During the transport, smart phone with the installed android application is attached to the windshield as shown in Fig. 4. a). Ten second interval calculation is performed based on the *Guide to the Evaluation of Human Exposure to Whole-Body Vibration"* [9] standard. At the end general marker point is generated with 12 calculated parameters. Based on the calculated data, markers are classified as (comfortable – green marker, medium uncomfortable – yellow marker, very uncomfortable – red marker). At the end Keyhole Markup Language (KML) file presented at Fig. 4. b) is created.

Fig. 4 *A) Implemented application usage, b) Google Maps Appearance of saved KML*

Klick on the marker shows the window with 12 calculated transport parameters. For the result presented in this paper only cars are used. As an example for measured transport comfort, one transport from Čačak to Belgrade, shown in Fig. 4 is presented. During transport 843 markers were created. Transportation statistic is shown in the Table 1.

Table 1 Transportation statistic at relation Čačak - Belgrade

Title	**Value**
Total interval number	843
Comfortable interval number	454 - 53.8%
A little uncomfortable interval number	363 - 43%
Uncomfortable interval number	26 – 3.2%

As shown, only 53% were comfortable, while 3.2% were very uncomfortable.

After several months of application usage, some roads were market more than once. In that kind of situation, there are markers from different transportation that are saved in some close range. Relation with multiple transportation is presented at Fig 5.

Fig. 5 *Relation with multiple transportation*

As shown, there are locations, marked with rec circle at Fig. 5. That contains multiple markers in very close range. This is situation where one marker representing a cluster would be more appropriate. It is also very important to mention that marked locations contains markers with different colors, which mean that different comfort levels were detected at the same locations. This could be consequence of different static and dynamic effects. Static reasons: in meanwhile, roads could be repaired so uncomfortable location can become comfortable. Dynamic reasons: sudden braking, car collisions or weather conditions could produce different comfort levels at the same location.

4 TRANSPORT COMFORT DATA CLUSTERING

As presented in previous section, after some period of the application usage, very large number of markers were saved to the database. At most used roads, several transportations were performed and multiple markers in very close range were saved. So, it was necessary to group these markers into cluster and extract one overall marker from one location.

For the purpose of the transport comfort data clustering Java Web application was created. If is realized as multilayer model-view-controller (MVC) application. Java server pages (JSP) were used for View part, and Java Servlets for the Controllers.

MySQL database with phpMyAdmin interface was used. Database schema consist of 5 tables shown in Fig. 6:

- Marker – represent one marker with all calculated parameters

- Cluster – represent cluster center and one overall comfort value
- Temp – temporary table for one transport markers upload before they were assigned to cluster
- Postmarker – represent markers after post clustering
- Setup – initial application setup with comfort threshold values and cluster radius.

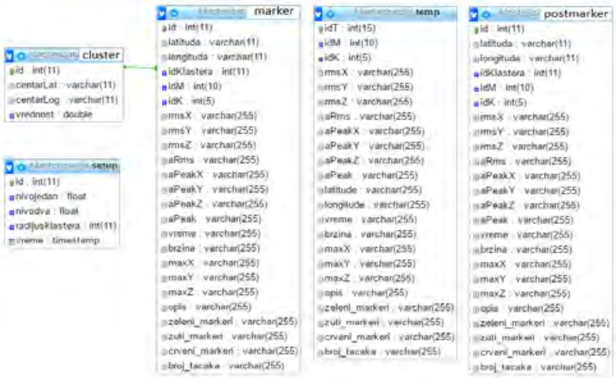

Fig. 6 *Database schema*

For the purpose of clustering (assigning markers to cluster) it was necessary to use store procedures. In this project three store procedures are used:

- get_lowest_distance(latitude, longitude, radius) - returns closest cluster in defined radius from the location market with latitude and longitude
- get_lowest_distance_2(latitude, longitude) - used in post clustering to return nearest cluster
- update_value(idCluster) - update comfort value for cluster with idCluster after marker is assigned to the cluster.

Besides KML file presented in Fig. 4. b) coma separated value (CSV) file is created. Web application interface is simple and consist off:

- CSV file upload form,
- Clustering action – setup cluster radius
- Post-clustering action – do post clustering
- Show map action

CSV file upload form is used to upload CSV file to developed web application into *temp* table. After upload, **clustering action** is performed with radius as input parameter. During clustering every marker is assigned to some cluster or new cluster is created if there is no suitable cluster to join. K-means algorithm [4] is used. After first clustering iteration *temp* table is deleted. Overall cluster comfort value is calculated as all cluster markers average comfort values. **Show map action** open the map with cluster markers as shown in Fig. 7.
Click on the cluster marker open the popup window with table data for every marker from the cluster. Beside table info window, in the bottom right corner there is map view only for markers from the clicked cluster marker. Cluster is marked with red circle with predefined up cluster radius.
Post clustering action is used to check if every object (marker) is joined to the nearest cluster center. If that is not the case, marker is transferred to nearest cluster and overall cluster comfort value is recalculated.

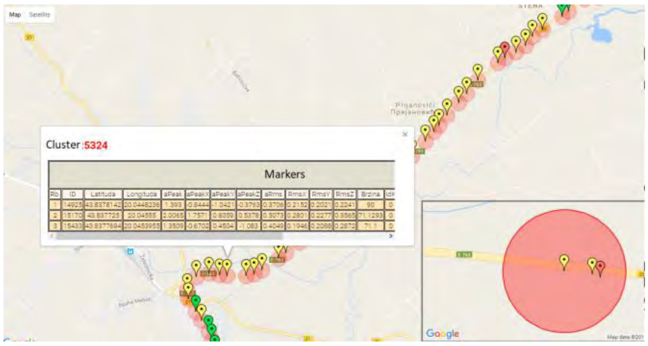

Fig. 7. *Road marked with cluster markers*

CONCLUSION

As a conclusion, clustering over large amount of data produce more suitable data preview. One information is presented to the users after data analysis. For the future work, more algorithms for overall comfort values calculation would be used, so newest data or data from some users would have a higher priority.

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SOME MODERN TRENDS OF AUTONOMOUS VEHICLES

Suzana JOVANOVI [1]
Miloš MILOŠEVI [2]

[1)] *Ministry of defense Republic of Serbia*
[2)] *University of Niš, Faculty of Mechanical Engineering*

Abstract

We live in a time of technological change that is unprecedented in its tempo, scope and depth of impact. Today, two potentially transformative technologies are autonomous vehicles and blockchain. Autonomous driving is one of the sectors that is not usually part of the blockchain world. According to today's standard of autonomous driving classification, only a small fraction of vehicles worldwide can reach the highest degree of autonomous driving ability. Blockchain autopilot is a cutting-edge technology – contemporary trend that is at the very beginning of its expansion and can bring a lot of improvements in activities such as transportation. Blockchain autopilot is a transparent, efficient, secure and open passenger platform with advanced autonomous driving technology, based on Blockchain's graphene base technology, which improves overall unmanned driving performance, constructs the next generation of intelligent transportation infrastructure, and leads the reform of all autopilot technology. The founders of this technology named it Vectoraic. Building a Vectoraic blockchain ecosystem is based on big data collected from Vectoraic OS. The public chain is the basic storage unit, and the data is encrypted with an algorithm. The private chain was extended to the public chain to decrypt the data. Full autonomy with an incredible percentage of security and precision is reaching Industry 4.0. The benefits of this technology are not only the high degree of security and precision, but also the availability, with a fairly low price, which is presented to the market. Not only does this technology bring secure transport capabilities, it also generates profits in cryptocurrency through data sharing and data validation.

1 INTRODUCTION

Intensive traffic modernization is one of the basic goals of a more economical and cost-effective development of the overall economy. This implies the need to continuously explore the development of transport technology, technology and organization in order to match the demand of the overall economy with the size, level, structure and quality of demand for transport services in domestic and foreign relations.

The development of new transportation technology has a significant impact on the price of goods, on the location of individual production facilities with a reflection on the normal functioning of the overall social reproduction, on the profitability of investments and on the level and structure of international exchange.

With the implementation of IT solution, traffic regulation has the effect of reducing costs and increasing passenger satisfaction, thereby indirectly reducing the number of traffic accidents. Future solutions will be based on the implementation of smarter and more environmentally sound vehicles and their connection to infrastructure facilities such as gas stations, parking lots, garages and further. The widespread use of advanced information technologies, in addition to vehicle communication with infrastructure, will allow vehicle communication between them (automatic maintenance of minimum distance to avoid collisions).

Examples of implementing intelligent transport systems are the integration of traffic control systems [1]:

- traffic flow management,
- traffic lights management,
- variable traffic messages,
- control of access to the motorway,
- speed check,
- parking management, etc.

Information provided by modern systems (vehicle tracking, navigation, e-toll collection, etc.) is usually transmitted over a 3G or 4G mobile network or other communication systems.

Fig 1. *Intelligent transport systems [13]*

2 ANALYSIS OF AUTONOMOUS VEHICLES

Autonomous vehicles are defined as "vehicles where there is movement without direct driver input related to steering, acceleration and braking," according to the National Highway Traffic Safety Administration. In this type of vehicle, the driver is "not expected to constantly monitor the pavement while the vehicle is operating on the autopilot system" [2]. This definition assumes that the vehicle will always have a driver. However, this is not necessary -

autonomous technologies are already able to perform all the necessary functions for safe movement of vehicles from A to B without boarding passengers.
The widespread use of autopilot vehicles may seem like a distant future - something you would expect in a futuristic movie. However, the reality is that some of the world's leading automotive and technology companies are already showing the first prototypes and are discussing the coming of the "next automotive revolution". The first tests of autonomous vehicles are already underway. And if you look closely at the vehicles on our roads today, you will see that many are adopting the many key technologies required for autonomous driving.

2.1. Technology overview

Autonomous technologies have been used productively in various applications for many years. One of the most obvious benefits is in aviation - it is considered normal for airlines to develop autopilot technologies as standard equipment. Other examples include fully automated metro and short-haul trains operating in multiple cities and airports around the world.
As with many technological advances, the military sector was the first to use autonomous vehicle technology. A significant example is the military use of autonomous mine clearance technologies. It saved countless lives by keeping soldiers and civilians out of danger until the mines were discovered and safely detonated or rendered impossible [3].
Some simple autonomous features, such as anti-lock braking system and driving control can be found in most vehicles. In addition to these supporting features, there are already many advanced features that can take over the element of primary control. An example is adaptive driving control, which has been integrated into selected vehicles in the past few years. This technology maintains a certain distance between a conventional vehicle or an autopilot vehicle.
In order to construct a self-driving vehicle, four basic interdependent functions need to be implemented. These are navigation, situational analysis, movement planning and path control [4], which are described in more detail in the following.

2.1.1. Navigation

Navigation is essentially route planning. More specifically, it creates and recalculates a digital map that includes information on locations, road types and settings, terrain and weather forecasts [4].
Today, vehicles perform complete route planning using the Global Positioning System (GPS). In a fully autonomous vehicle, however, navigation is enhanced by the integration of vehicle-to-vehicle (V2V) communication (Figure 2).

This is supported by the continuous exchange of data between vehicles through communication systems such as wireless local area networks (VLANs). With V2V communication, the autonomous system can recognize critical and dangerous situations at an early stage, and receive the necessary safety related information within a second [5].

Fig 2. *Security information is currently transmitted by V2V communication [3]*

2.1.2. Situational analysis

The situational analysis monitors the environment through which the vehicle moves to ensure that the autonomous system is aware of all relevant objects and their movements.
Visual image recognition techniques, broadly defined as video cameras, identify relevant objects in the environment such as other vehicles, pedestrians, traffic signs and traffic lights (Figure 3) [4]. In addition, precise positioning information can be obtained using markers embedded in the infrastructure.

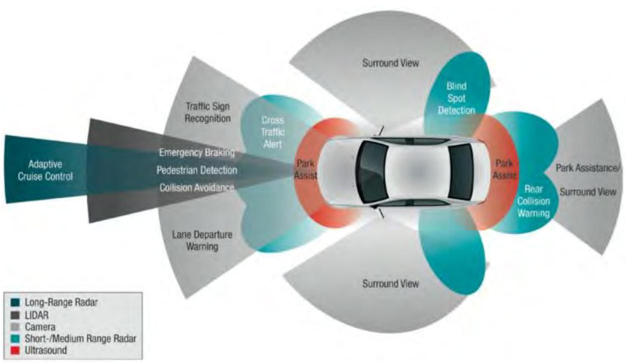

Fig 3. *Situational analysis and its use of different sensors [14]*

The downside is that this solution requires significant investment. Other key techniques are the use of radar and ultrasonic sensors. These solutions create images with electromagnetic waves and ultrasonic waves, respectively. Although visual image recognition depends on good weather, radar and ultrasound technology can reliably operate in difficult weather conditions such as fog or heavy rain.

2.1.3. Movement planning

Motion planning monitors vehicle movement. It does this by using sensors that determine the precise course of motion over a period of time. This course must ensure that the moving vehicle stays in its lane and continues in the right direction as defined by the navigation system so that the vehicle avoids collision with static and dynamic objects identified by situational analysis.

The direction is determined by the current position of the vehicle and the route, avoiding any static objects detected. Speed and direction adjustments must be made, and they are based on a number of variables. Appropriate speed, for example, depends on the width of the lane, the preferences and layout of the passengers, the speed limits on a particular section of the road and much more. And one of the major challenges is to avoid not only static objects but also dynamic objects, as this requires the prediction of their future movements.

2.1.4. Path control

Path control manages the execution of pre-planned changes in speed and direction while observing and maintaining ride stability. Acceleration or braking and steering procedures are performed by the autonomous system[4].
Driving stability is measured by comparing the expected with the actual changes that occur after a change in speed or direction. If there is a large discrepancy between expected and actual changes, the autonomous system adjusts to return to stable driving mode.

3 "BLOCKCHAIN" TECHNOLOGY

In the modern, information society, information is of great importance. The amount of (confidential) information we have exchanged and have exchanging has increased significantly, but the way information is exchanged and stored has not changed much since the 1990s. If it is information whose integrity we want to protect, then the storage system needs to have the following characteristics [6]:
• Information moves through a secure network;
• Information cannot be modified during or after writing;
• Only an authorized user has the right to use digital or material goods related to information;
• The speed of information exchange must be as high as possible;
• Any interested user can easily review the information;

Blockchain technology enables the distribution of digital information between all nodes participating in the system. Therefore, each node maintains its own copy of each relevant information and does not need a central information control body. Control is also distributed, using validation mechanisms, each node can be sure that the information written on the blockchain is correct. This technology was created for the needs of the digital currency Bitcoin, which was introduced in 2008 and started operating a year later (2009).
Blockchain provides maximum protection of record integrity using cryptographic methods. Records are distributed, each node in the system has equivalent data, which is achieved by consensus algorithms, the most famous of which is the proof-of-work and proof-of-stake algorithm.
The records cannot be changed or disturbed. A blockchain is made up of blocks interconnected into a chain. Each block contains a series of records. The blocks are connected by an algorithm that uses a cryptographic hash function. The link between the blocks cannot be forged unless the attacker has huge computer resources at his or her disposal.

3.1. P2P network (peer-to-peer)

Copies of Blockchain are distributed to multiple computers around the world, where full or partial copies of the data in blocks are stored on the so-called nodes, and each computer included in the network system checks the validity of all the data entered, thus confirming the security of the data and then adding them to its database. This specificity of the Blockchain is called a decentralized data management system. This is the safest method of storing information instead of keeping the information in one database so far. In this way, multiple copies of identical data are stored on different devices on the network, in different locations, because there is no central server [7].

Information is transmitted directly between users, and it is specific that each user can be directly connected to only a few other users, which is known as the peer to peer network. This way of storing data implies that if only one point is damaged or lost, copies of the data remain securely stored in multiple places. Accordingly, if there is a change of data without the consent of the administrator, there is original data in several other places indicating its original state, ie. Changes, additions, falsifications and deletions of the originally created data are prevented.

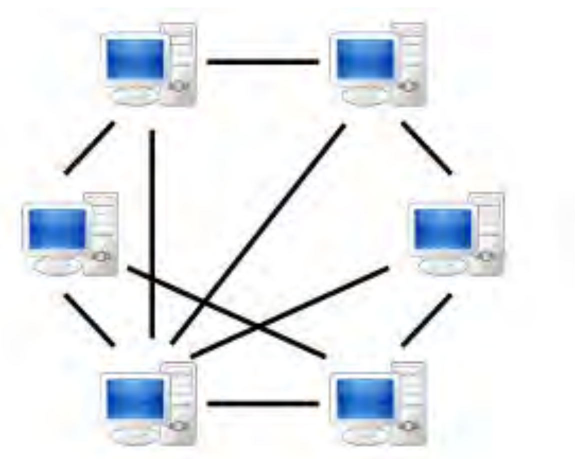

Fig 4. Decentralized P2P network [15]

3.2. An example of a "Blockchain" transaction

All participants in a Blockchain transaction are connected through nodes, and mathematical logic finds free nodes and forwards the transaction from nodes, to nodes, on the basis of the fastest flow, to pass it to the destination.
In order for institutions to use Blockchain, it is necessary to provide the following [8]:

- Each participant in the transaction must be uniquely identified
- Each participant must be part of an integrated network
- The participant can be a direct or indirect part of the network

The difference with the existing transaction system is that the Transaction Block, on its own, finds its unique and shortest path of transfer from node to node.

4 "BLOCKCHAIN" AUTOPILOT

Blockchain provides shared access to the data being distributed. This maintains the confidence and privacy of the participants. Blockchain has influenced every vertical and domain of the industry and no wonder the automotive industry is influenced by this technology. Real-time monitoring, auditing capability and scalability are key factors favoring blockchain technology in vehicle connectivity, cyber security and autonomous vehicles.
There are 6 possibilities of using Blockchain technologies in the automotive industry, these are [9]: mobility solutions, automotive IoT (Internet of things), smart manufacturing, vehicle monitoring, insurance requirements, supply chain.

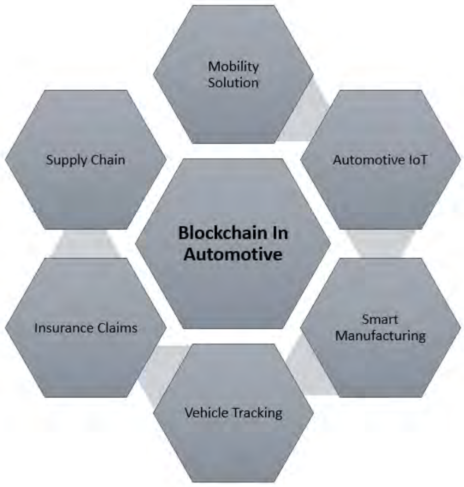

Fig 5. Automotive industries where blockchain technology is used [9]

Although blockchain affects various success factors, its use in car faces external challenges such as lack of expertise, knowledge, practical training, scalability, security, low industry standardization and geographically variable regulatory regimes.

4.1. Synthesis of Blockchain Technologies and Autopilot (Vectoraic)

Autonomous driving is one of the sectors that is not usually part of the blockchain world. According to today's standard of autonomous driving classification, only a small fraction of vehicles worldwide can reach the highest degree of autonomous driving ability. Although all companies have realized the capabilities of autonomous artificial intelligence driving, the autopilot technologies of big companies such as Baidu, Google, Uber, Tesla have not made much progress due to poor processor technology. Limiting the detection range of existing detectors is a problem due to the fact that the vehicle moves from high speed to full stop, requiring physical braking. There are also some technical limitations on sensors used in autonomous driving.
Vectoraic is a transparent, efficient, secure and open passenger platform with advanced autonomous driving technology, based on Blockchain's graphene-based technology that improves overall unmanned driving performance, constructs the next generation of intelligent transportation infrastructure and leads the reform of the entire autopilot technology.
Building a Vectoraic blockchain ecosystem is based on big data collected from the Vectoraic OS. The public chain is the basic storage unit, and the data is encrypted with an algorithm. The private chain was extended to the public chain to decrypt the data. At the same time, Vectoraic Exchange and Vectoraic Sharing based on the public chain provide a good platform for trading and sharing car data, and BaaS based on the private chain enables Vectoraic partners to provide more accurate customer service through data decryption. In addition, BaaS also provides users with a good reward for driving through Vectoraic and uses an incentive mechanism to revitalize the entire Vectoraic ecosystem [10].
One of the most important use cases of Vectoraic is definitely the project to achieve Industry 4.0 automatic driving technology. Its basic technology is patented in the US, and the software patent number is PCT / IL2018 / 050085. Vectoraic technology has been applied in the field, in the Israeli military industry, and the next step will be to establish a laboratory at the Viseman Institute and set up a research and development base in Guangzhou In China.

4.2. The structure of the Vectoraic "Blockchain"

Vectoraic has created a road platform based on automatic driving and blockchain technology to provide technical and data support that is being used. Traffic is an area that we all use that can make a difference in quality of life. Not only does this area of economy give great benefits to society, but it also significantly improves the quality of human life if sufficiently developed. The global travel market is extremely large. Vectoraic tries to combine unmanned technology with the benefits of blockchain to optimize and improve the safety of unmanned and other vehicle functions so that unmanned travel can be more quickly populated, changing existing travel fields.
Vectoraic can generate behavior by sharing automotive auto data, and Vectoraic provides technical support to companies. To this end, Vectoraic selects graphene as the basic technology architecture for building the Vectoraic public chain and introduces a number of key business components such as Vectoraic Private Chain, Partner Authentication, User Authentication, Vectoraic Wallet, Vectoraic Network2, Vectoraic OS, to ensure that the whole platform is a closed loop.
Vectoraic adopts the basic structure of graphene and records data collected from Vectoraic OS through the public chain. Users (passengers) can use a shared, non-member road platform (Vectoraic Sharing) to load a Vectoraic OS autonomous vehicle using VT (VT is a Vectoraic Token in short, VT is a digital currency in the Vectoraic circulation). Meanwhile, Vectoraic OS provides autonomous vehicle data and other behavioral data[11].
Users (drivers) can exchange data with other autonomous vehicles with Vectoraic OS on a VT exchange platform, can enjoy full transparency through the Vectoraic exchange platform, and can also get a free car performance report through an open platform (BaaS) and better understand the real situation of the car. The private chain has the function

of encrypting public chain information, the Vectoraic team builds BaaS on the private chain application layer[11]. Subcontractors (such as insurance companies) receive a specific private key for specific public chain information from BaaS by VT. Through this data, associates can achieve more accurate business development.

4.3. Vectoraic mechatronic applications

4.3.1. Automatic distance detection technology-First BLOS (beyond-line-of-sight)

Vectoraic is the only autonomous driving prediction system developed based on blockchain aircraft crash detection technology and implements unique risk prediction by distributing the frequency of any digital device in each risk area. Vectoraic has unique V2X (Vehicle to X) technology[11]. Currently, technology in the market can only recognize visible objects within a certain range, but Vectoraic's revolutionary technology can receive data between transmission devices (such as mobile phones), sensors and perception cameras, can predict areas of risk and send wounds collision warning signals.

Fig 6. Data flow through the Vectoraic system [16]

Vectoraic accepts the principle of multiple operations, interconnects all moving objects, sends a signal source to the cloud processor, calculates and analyzes through the Vectoraic algorithm, and sends a picture of a possible accident to the user via an alert instruction[11]. In signal capture, distribution technology after subversive design and algorithm optimization has also been granted a patent.
Generally speaking, the world's only remote prediction system is the largest breakthrough in autopilot technology from Vectoraic and can exclude 96% of collision risks at 2 kilometers far beyond the maximum range (300 meters) detectable by current autopilot technology.

4.3.2. The most efficient image processing technology in the world

Compared to the image data collected from Google Maps, Vectoraic implements the highest vector data processing system. Using intelligent rigid self-steering technology and slant angle shifting technology, Vectoraic is able to perform 3D omni-directional detection and depth perception to the target.
With high resolution laser detection, the scanned vector will be measured at 360 degrees. Then the volume data is transferred to the background, and the massive fragment data is automatically merged into a perfect vector map. Based on the neural network algorithm, accurate risk analysis is performed automatically. The efficiency is 300 times that of the Google satellite map.

Fig 7. Integrated circuits as the most significant component of Vectoraic technology [11]

4.3.3. The most advanced and smallest vehicle radar system

The principle of operating radars with phase arrays is very important for understanding the system. Normal radar has a lot of radar blind spots. Phase array radar is mainly used in the military. Vectoraic is the only autonomous driving company that applies phase-series radar technology.
There are currently two types of self-driving sensors, namely camera and radar. Among them, the performance of laser radars in extreme weather conditions, such as rain and snow fog, is poor, the millimeter-wave radar cannot accurately model the surrounding obstacles and cannot perceive pedestrians [11].
The antimonizing ability of ultrasound radar is poor, the distance is short, and almost everyone has a defect. Therefore, some companies are developing a combination of different sensors, such as a combination of "camera + millimeter wave + radar + ultrasound + ic sensor" and so on, but since the price is extremely high, it is not practical to use in mass production of vehicles [12].
Vectoraic uses the most advanced and lowest in the world, a 360 degree radar system and a phase array that is only 5 cm tall and 10 times smaller than the Google radar system. The radar is fixed and can achieve 360 degree space detection without rotation. Reaction speed is 100 times faster than Google radar system.

4.3.4. The fastest and smallest operating system in cars

Traditionally, data must be stored in memory for processing by a central processing unit (CPU), and an accelerated processing unit (APU) using Vectoraic allows the data to be stored directly in memory and directly processed without input / output, greatly improving performance operations, and the operating speed is 1000 times higher than the current chip. In addition, as efficiency increases, electricity consumption is also significantly reduced.

4.3.5. World's smallest night vision sensor

The vectoraic night vision sensor is based on the world's fastest processing unit (APU). In addition, no gas cooling system is required for excellent performance, and can also achieve clear perspective and target induction in a completely dark, foggy, rainy and snowy environment.

4.3.6. Super high performance vectoraic hardware

Super high performance vectoraic hardware has a price ratio of only 1% of the market price. Vectoraic provide a more cost-effective solution, 90% lower than the current market price. Google, Uber, GM and Inter hardware costs between $ 25,000 and $ 80,000. The total cost of Vectoraic is only $ 2,500 and the cost is reduced to 10 percent.

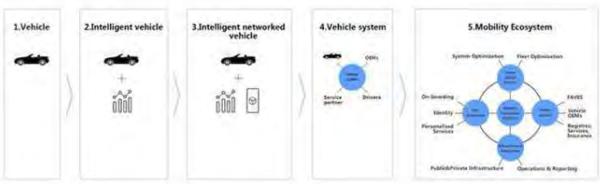

Fig 8. The complexity of blockchain autopilot technology [11]

5 ADVANTAGES OF "BLOCKCHAIN" RELATED TO AUTOMATIC DRIVING

Prevention of hacking attacks

The prerequisite for deploying automated technology is full coverage and access to the Internet, but once the Internet is connected, the hacker will exploit the vulnerabilities in the system to remotely locate cars at risk of harm. How to prevent hackers from attacking and how to protect data security is an urgent problem that is addressed by autonomous systems. Blockchain is the best choice for protecting data and preventing hackers from invading through data encryption.

Eliminating credit risk of centralized nodes

Centralizing nodes means that automakers and service providers are likely to take great credit risks with data storage, data usage, and data security, but the Blockchain distributed consensus algorithm can largely eliminate the risks that centralized nodes bring.

Improving system efficiency

With blockchain technology, applications and vehicles can make offline connections, and data does not need to flow through third-party servers. Blockchain makes the autonomous vehicle no longer have to rely on a central system to allocate and store all driving information, and saves on the central organization's heavy service costs.

Transparency and reliability

The code is the law. A decentralized blockchain-based consensus algorithm allows Vectoraic to provide users with a technology trust system. The entire network eliminates the risk of isolated data swelling and monopoly of data through distributed nodes.

Troubleshoot responsible confirmation

By accessing Blockchain technology, a distributed accounting system can capture all data from vehicle manufacturers, software vendors, and service centers and ensure liability for an accident by the fact that interactive stored accident data has not been altered through distributed nodes.

CONCLUSION

With the development of technology, the claim that who owns information possesses power is also strengthened. When information, sometimes innocuous, is in the hands of the wrong people, it can cause a lot of problems. With the development of technologies, the flow of information grows and therefore the availability of information to people who can abuse it.

The new way of exchanging data through peer-to-peer technology is revolutionizing the way we communicate and distribute data. The possibility for more users to "keep accurate data" and without which the data cannot be changed (multi-user means the millionth digit of users) creates a high degree of accuracy of data, and thus brings security to all spheres of the economy.

The need for people to get from point A to point B increases with globalization. Increasingly available to people are travel, travel infrastructures and used vehicles that are being refined and upgraded with cutting-edge technologies that until just a few years ago could not have been imagined.

By providing a wide range of key benefits, including improved road safety, greater fuel efficiency and reduced environmental impact, autonomous driving technologies will surely affect our daily lives. We are just beginning to realize the magnitude of this impact.

In the near future, we are likely to see improvements to existing driver assistance features, with a particularly strong focus on safety.

Full autonomy with an incredible percentage of security and precision is reaching Industry 4.0. The benefits of this technology are not only the high degree of security and precision, but also the availability, with a fairly low price, which is presented to the market. Not only does this technology bring secure transport capabilities, it also generates profits in cryptocurrency through data sharing as well as data validation.

Vectoraic presented its patent to the public in mid-2017. With this level of advancement and the opportunities they provide, it is expected that this technology will expand not only in traffic through vehicle technologies or in logistics, but in all branches of the economy and in the lives of individuals.

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Contact address:
Suzana Jovanović
Ministry of defence Republic of Serbia
Regional center of Ministry of defence for Niš district
Beogradska bb, 18000 Niš
E-mail: princezzaofnish@hotmail.com

3. TRAFFIC ENGINEERING, URBAN MOBILITY AND CITY LOGISTICS

UNIVERSITY OF NIS FACULTY OF MECHANICAL ENGINEERING
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til 2019

TQM TOOLS IN SUPPORT TO URBAN MOBILITY SHIFT: EXPLORING POSSIBILITIES TO TRANSFER EU PRACTICE IN SERBIA

Marijana PETROVIĆ[1]
Nataša VIDOVIĆ[1]

[1)] University of Belgrade,
Faculty of Transport and Traffic Engineering

Abstract

New paradigm of the urban mobility planning envisioned in European Union (EU) policy package and "incarnated" in SUMPs (Sustainable Urban Mobility Plans) invoked researchers from the field of the quality management (QM) to devise tools that will help to keep SUMP on track and lead the activities of different stakeholders towards common goals. The impetus was given by the European Commission itself, who in Transport White Paper from 2011 stressed the importance of obtaining Urban Mobility Performance and Sustainability Audit Certificate. During years various QM schemes were devised in support to urban mobility (mostly as result from large projects), some focusing on specific themes as walking, cycling or overall mobility shift. In this paper we give a review of existing European QM tools for urban mobility with focus on TQM tools and specific theme - cycling. Based on the gathered body of knowledge we propose a specific tool for assessing the cycling policy in Serbian urban environments.

Key words*: quality management, urban mobility, cycling, European Union, Serbia.*

1 INTRODUCTION

Transportation, as the backbone of urban activities, is in the spotlight. Urban environments need to sustain their dynamics, while the problems are piling up. Congestion, air and noise pollution along with road accidents are major issues in urban areas which are accounting nearly 80% of EU population [1]. To cope with the challenges EU is relying on integrated and participative approach in urban mobility planning. In the core are Sustainable mobility plans (SUMP) as the central concept of European Union‘s (EU) policy package for urban mobility [2]. It is in fact a framework for putting mobility management (MM) in practice. In essence MM is about urban mobility shift - managing transport demand by promoting and encouraging the use of alternatives to passenger car. So called "soft measures" (like campaigns, coordination of activities of different stakeholders, etc.) are in the core of MM. They are seen as indispensable in assuring the effectives of "hard measures" (e.g. new bike lines, 30km/h zones, restricted access to city centre, etc.). One of the major issues on MM is lack of in systematical developing and deploying the measures in accordance to city‘s SUMP [3]. Accordingly, relevant actors (decision makers, planners, practitioners, academics, etc.) are searching for adequate concepts and tools that will support operationalization of MM i.e. help to move from policy on paper to results evidenced in practice. One of the core activities in this regard is monitoring and evaluation.

A prominent stream of research is on linking QM and MM. Quality Management (QM) is about systematic managing of all processes within an organization with the aim to deliver high quality products/services. The term systematic is used to pinpoint to the common way of implementing QM, on the basis of standardized models for QMS (Quality Management System). ISO 9000 standards are the mainstream model for QMS but during time some more mature and comprehensive approaches have emerged, like IMS (Integrated Management Systems), TQM (Total Quality Management) and business excellence. IMS is about merging different management systems with QMS (like EMS- Environmental Management System, OHSAS - Management System for Occupational Health and Safety) in order to meet the needs of different stakeholders (customers, employees, society). TQM follows the same logic as the one in IMS - an integrated and structured approach holding all parties involved (customers, employees, etc.) in a continuous process of improving overall quality. It is commonly associated with business excellence models [4]. When it comes to monitoring and evaluation ISO 9000 standards are aimed at so called quality audits (QA) while TQM and business excellence models are oriented towards self-assessment (SA). Both approaches are about comparing the effectiveness of organization‘s QM against set of criteria in order to underpin improvements. As extensively elaborated in [5] SA unlike QA can drive and guide improvements while QA is more about providing a starting point. Also, SA is more about combining different QM tools and involvement of different stakeholders while QA is more oriented towards common evaluation procedures coordinated by trained auditor. Additionally as highlighted in [5] it is advisable to mix these approaches in a way that QAs would be used for evaluating ‗hard controls‘‘, while SAs is for ‗softer‘‘ concerns and tracking improvements.

Regardless the differences in underlying logic both approaches are seen as prominent for resolving the above discussed issue of systematic approach in defining and applying MM measures in accordance to SUMP. Maybe the biggest confirmation of this is given by ELTIS - The Urban Mobility Observatory in EU, which included QM in its SUMP audiences and even glossary of the most important terms. Also ELTIS offers several practical examples of QM for urban mobility (projects funded by EU on different topics).

In this paper we follow the work of EU on QM for urban mobility with aim to enlighten the added value of this idea. We also consider how EU experiences can be used to frame TQM approach for urban mobility in Serbia using cycling as a topic of interest.

The paper is organized as follows. In the next section we give insights on why and how QM is used in support to urban mobility in EU. Section tree is about selected European QM and TQM schemes for cycling. In the section four we propose a framework for monitoring and evaluation (M&E) of cycling policy in Serbia, as one of the core activities in QM and TQM models. The paper ends with main conclusions drawn and future research steps.

2 LINKING QM AND URBAN MOBILITY - THE CASE OF EU

Within the previous section we have explained the conceptual background of the relationship between QM and MM. However, in terms of putting this idea into practice the strongest impetus was given by the European transport policy. The Transport White Paper [6] explicitly states that regional development and cohesion funds should be related to cities with independently validated Urban Mobility Performance and Audit Certificate. Furthermore, the SUMP Annex to the Urban Mobility Package [2] includes allegation that local authorities need to have instruments to validate the quality their Sustainable Urban Mobility Plan. The interest of EU in standardized way to approach MM started even before Transport white paper (2011). In 2009 European Committee for Standardization (CEN) published ―Code of practice for implementing quality in mobility management in small and medium sized cities" [7]. It is not an official standard but rather a guide for city representatives.

Several audit and self-assessment schemes were developed in EU related to general (e.g. SUMP, mobility shift) or specific urban mobility issues (e.g. cycling, safety, etc.). In line with *ex ante* condition for accessing EU funds, these schemes are developed within large regional projects. A review of these initiatives is given in [8]. Since some new assessment instruments were introduced in the meantime, we offer an up to date overview. It is presented in Table 1.

Several conclusion about these models can be drawn.

First there is a shift in a central domain - from specific to general. Instead of focusing on just cycling, or energy efficiency, nowadays approaches are all about SUMPS. This is logic since SUMPs are becoming widespread in EU and since they encompass all aspects of urban mobility.

Second, devising a specific monitoring and evaluation instrument is a part of all approaches but not all of them are based on QM or TQM models. Those who are (first seven in Table 1) include audits and/or SA in their QM or TQM models. The other three are only about M&E without grounding it on QM or TQM. For example within CH4LLENGE project SUMP monitoring tool is devised [9], while ENDURANCE provides a self-assessment questionnaire.

Although the vast of these projects officially ended they are still an important part of SUMP monitoring. For example the report of the project SUMP-UP from 2018 [10] relays on findings of previous QM projects and provides an overview of best practice exemplars i.e. cities with quality control and quality assurance schemes for SUMP. Findings of previous projects (e.g. CH4LLENGE) also served ELTIS as a baseline for developing contemporary SUMP self-assessment tool.

It is a comprehensive web-based evaluation tool which helps cities to assess the compliance of their plan with the European Commission's SUMP guidelines [11]. As these guidelines are regularly updated it is recommendable for cities to perform self-assessment on regular basis.

Table 1 EU initiatives on QM for urban mobility

Project	QM or TQM conceptual background	Domain	Duration
MaxQ	x	Mobility Management	2006-09
BYPAD	x	Cycling	1998-2008
Eco Mobility shift	x	Eco- mobility	2011-
ISEMOA	x	Accessibility of public transport	2010-13
QUEST	x	Energy efficiency	2011-13
MEDIATE	x	Inclusive urban transport system	2008-10
ADVANCE	x	SUMP	2011-14
ENDURANCE		SUMP M&E	2013-16
CH4LLENGE		SUMP M&E	2016-
SUMP SA Scheme		SUMP alignment with EU guidance's	2016-

Maybe the biggest added value of all EU QM based approaches to urban mobility is that they serve as an inspiration and as a knowledge source for cities who are redesigning their urban mobility planning towards SUMPS (e.g. Serbia). For example, ADVANCE was used to develop a benchmarking scheme for national safety system Serbia i.e. to evaluate the work of relevant institutions [12]. Since the aim of this paper is to propose a framework for QM based scheme for cycling policy in Serbia we will first give more details on existing EU approaches in this domain.

We will start with the BYPAD as the most known and most comprehensive. After we will explain in brief two other initiatives (one out of the Europe), which unlike BYPAD are in top-down setting. This means that instead of local authorities they were induced by the Ministries responsible for transport.

3 TQM AND QM MODELS FOR LOCAL CYCLING

During recent years the need for a high-quality cycling policy has been better recognized. Searching a way to improve local cycling policy points to various QM based evaluation instruments, some already used to estimate cycling measures and programs in several countries.

3.1. BYPAD

BYPAD (Bicycle Policy Audit) is one of the most known models for cycling policy efficiency and effectiveness assessment. It is an instrument that enables authorities to estimate and improve the quality of their own cycling policy based on TQM concept. The core element of BYPAD is the questionnaire that includes nine aspects (modules) of cycling policy for smaller and larger cities/regions.

Policy makers, administrative officers and user groups fulfil this detailed questionnaire, which then provides insights in different opinions and estimates on development level. There is a series of multiple choice questions for each module and the quality is appraised on the scale from 1 to 4. If some measure has not been implemented it is scored with 0. In this way BYPAD determines the weakest links in the quality chain and indicates where improvements are needed [13].

The key characteristic of BYPAD approach is the fact all stakeholders are actively engaged in the quality improvement process. The audit process is monitored by an external consultant who is certified BYPAD auditor. Interim and final revision reports, written by the auditor, represent a detailed list of audit process documentation. As a result of BYPAD audit process, the city/region earns points for each of nine modules and for cycling policy as a whole. These results indicate advantages and disadvantages of city cycling policy [14].

Audit procedure is regularly repeated and thus allows to determine what areas are progressing and where further actions are needed. After finishing BYPAD audit the city/region gains the label of BYPAD quality, as well as BYPAD certificate. In this way the active engagement of decision makers, administrative bodies and citizens on making high-quality cycling policy is acknowledged. This increases city chances in applying for EU funds.

3.2. Cycle Notes

Cycle notes is an initiative launched in Australia in 2003 with the aim to help local governments to set Total Quality Management (TQM) for cycling and to measure continuous improvement against series of mile-stones through scorecards. Scorecards are designed to assist in determining the levels of effort required by each part of the organization to achieve the best possible outcomes for improved safety and increased participation in cycling. The planning and ongoing development, design, construction, maintenance and budget are the main areas monitored by local government. Detailed description of these scorecards can be found in [15], and here we will present them in brief.

Scorecards are divided in mentioned five areas, counting in total 11 scorecards. First step by local government is to indicate the level of progress to date by marking the current position on each scorecard (0-10); second step is to indicate the levels of achievement required on an annual basis and the goal on each scorecard; and in the end to assign a date and position responsible for achieving each milestone. After the scorecards have been filled out, information from each individual scorecard can be transposed onto a summary table [15]. This will give an immediate picture of the entire process. It is recommended that the local government reviews progress towards the targets annually. One of the conclusions is that the needs of bike riders can be met more effectively and economically when TQM approach is adopted.

3.3. Cycle Balance

The Dutch Cyclists‘ Union (Fietsersbond) has developed Cycle Balance with purpose to measure the efficiency and effectiveness of cycling development efforts. This benchmarking project was financed by Ministry responsible for transport. The primary objective of Cycle Balance was to encourage local government to adopt proper bicycle traffic policies that include management tools such as benchmarking and self-assessment. Details about this initiative can be found in [16].

The Cycle Balance assesses ten different dimensions with 24 sub-dimensions of the local conditions for cyclists. This part of the project contains four questionnaire surveys for the municipality. A questionnaire on cyclist‘s satisfaction is used to assess if the cycling conditions meet the requirements of the day-to-day cyclists. To assess the quality of the local cycling infrastructure The Quick Scan Indicator for Cycling Infrastructure is used. For each of the participating towns a report is obtained giving an adequate, objective and comprehensive picture of the local cycling conditions.

The results are compared with existing and developed standards and average scores of all 100 towns and Dutch towns of roughly the same size are obtained. In this way, the towns gain clear understanding of the strong and weak aspects of their cycling policy and are able to compare their efforts and results with those of other (comparable) towns. In addition they can reliably determine which aspects most urgently need improvement. As discussed in BICY Project report on best practices in cycling [17] the most important result of City Balance is a positive correlation between the actual bicycle-use and the scores on the nine other dimensions of the local cycling conditions.

4 FRAMING TQM SCHEME FOR SERBIAN CYCLING POLICY

Cycling in the modern world is growing in importance, both in terms of recreation means and transport mode. According to the number of bicycles and their usage compared to the total population of the country, Holland is in the first place, followed by Denmark, Germany, Sweden and Norway [18]. Their experiences point to the connection of the quality infrastructure and the amount of cycling. Most of the European cities have gradually been freeing the busiest parts of their centres from cars by providing efficient and various means of public transport, and by the development of non-motorized transport. In those countries, the usage of such modes of transport has been urged by a systemic approach of the country and the local communities, as well as by raising awareness on the cycling advantages.

Even though there is greater alertness of the need for proper cycling policy in the Republic of Serbia, this field has not yet obtained the attention it deserves. The guidelines for the development of cycling are scattered within various strategic and planning documents (general urbanism plans, regional spatial plans, the strategies of the development of cities and regions, etc.), while concrete measures and actions have remained undefined and unclear.

The majority of towns and cities in Serbia do not have adequate traffic infrastructure that could meet the needs of cyclists and make this form of transport safer and more attractive [19]. Besides the lack of compact cycling infrastructure, the exposure to risks in traffic, dispersed and disorganized network of bicycle lanes there is also a lack in systematic approach in cycling planning and policy. This also falls from the lack of well-established SUMPs for Serbian cities.

Based on gathered body of knowledge on EU TQM schemes for cycling in this paper we propose a general framework for evaluation of cycling in Serbia. Devising complete TQM model and accompanying self-assessment scheme is a demanding tasks and out of the scope of this work. Instead we focus on key building blocks of such approach. The aim is to lay foundations for cycling improvement process in Republic of Serbia. Inter alia, the proposed framework is based on the self-assessment principle, which contributes to the critical consideration of cycling policy from various aspects. The main goal is to support local authorities in providing high-quality cycling conditions and bust modal share of bicycle in Serbian urban environments.

Following the EU recipe on TQM for cycling, a total of five basic phases are proposed:

1. Forming cycling monitoring&evaluation work group
2. Gathering body of knowledge
3. Devising a scorecard
4. Putting scorecard into practice
5. Adopting cycling improvement plan

They are explained in details in subsection that follow. All phases are mutually interconnected as illustrated in Figure 1.

4.1. Forming cycling M&E work group

First step is to establish cycling work group (a team) at city level. There is no a clear rule for members‘ selection since their number and profile depends on the organization of city administration, as well as on city‘s transport system characteristics (e.g. has PT system or not). Far the most important is to achieve diversity of the group in order to increase the credibility of assessment results and improvement activities steaming from them.

We propose to relay on stakeholder mapping tool, a part of SUMP Guidelines (action 1.6) [11]. This means to structure the team around three categories: Primary stakeholders (citizens, cyclists, cycling associations, etc.); Key actors (cycling policy makers, mayor, urban planners, academics, etc.) and Intermediaries (public transport and infrastructure operators, public administrations, police, media, etc.). We also recommend that the coordination of group activities should be entrusted to the city administrative who is responsible for transport.

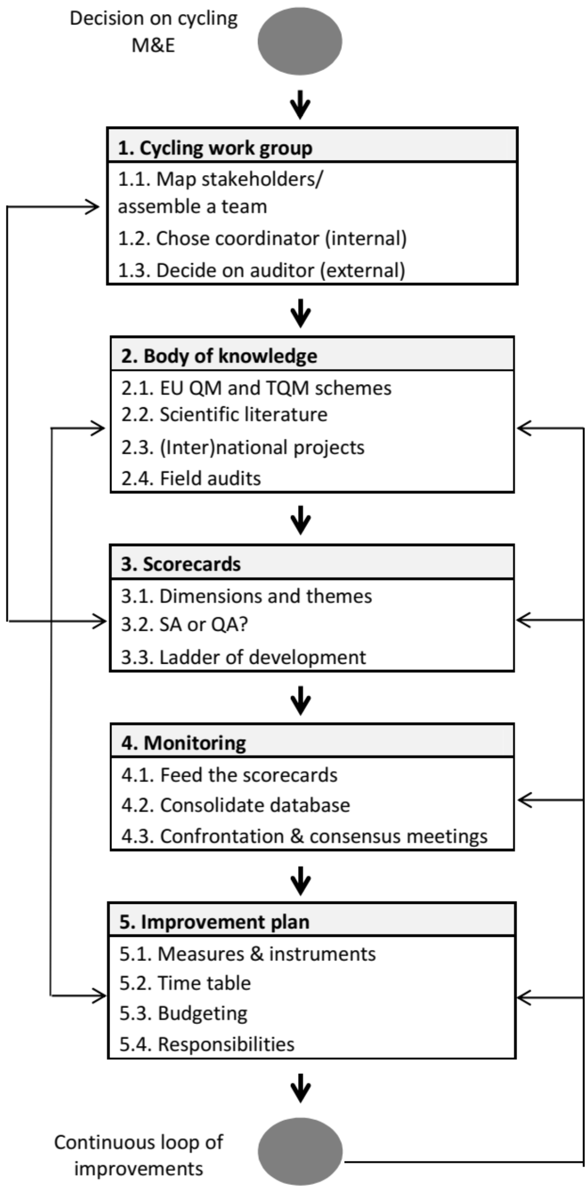

Fig. 1 *M&E scheme for cycling*

4.2. Gathering body of knowledge

The second step includes establishing body of knowledge /evidence using: relevant and up to date scientific literature, projects reports, policy documents, land use plans, urban mobility plans etc. Besides already elaborated EU QM and TQM schemes we recommend to rely on CIVITAS and ELTIS databases on good practice exemplars of cycling policy. From the academic perspective we propose to start with works of Gullon et al. [20], Pikora et al. [21], Silva et al. [21], Bojkovic et al. [22]. In [21] new audit schemes are introduced with emphasis on cycling. In [23], authors set a framework that helps decision makers to track prospects for reducing car use in relative context by extracting practically applicable information basis (including data on cycling). In [21] comprehensive insights on factors of cycling adoption are presented. A recent study [22] provides valuable signpost on how to organize workshops and similar events in order to track potentials for the development of cycling.

In this phase it is also recommendable to enrich desk research with field data. In this respect visual inspection of research area is of great value. We propose to use some good practices of so called Cycle field audits. The example is New Zealand's Cycle Audit [24].

This phase ends with drafting thematic fields that need to be subjected to thorough and regular assessment in the next phases.

4.3. Devising the assessment mechanism - Scorecard

The third part follows the result of the previous phase and is focused on gathering relevant data through tailored made questionnaire. In this phase we do not strictly label the process as self-assessment or audit. In essence they both come with the same purpose (see [5] for thorough discussion). For urban mobility the audit may be more rationale because it ends with a certificate for local authority which is a precondition to access EU funds. However in this case it is not about designing an own audit scheme but to simply apply some of the existing (like BYPAD) so to receive something that is recognizable in EU. On the other hand, as discussed in [5], compared to QA, SA is proved to be more in help with linking results with follow-up actions meaning that SA allows to incorporate results in directly into the transport planning process. Here we propose to combine elements of BYPAD audit, ADVANCE audit, and self-assessment based on scorecards from Cycle notes. There are two questions of interest here: TQM modules (evaluation domains) and proper scoring system.

To address the first issue we have reviewed the modules from EU TQM cycling schemes and identified seven most common i.e. overlapping domains (Table 2) which we will further explain.

Table 2 Common „modules" in EU TQM schemes and proposition for the Scorecard introduced in this paper

QM Modules	*BYPAD*	*Cycle Notes*	*Cycle Balance*	*Proposed Scorecard*
User needs	●	●	●	●
Leadership	●	●		
Policy on paper	●	●	●	●
Means & Personnel	●	●		
Communication & Education	●			●
Target groups & Partnerships	●	●		●
Complementary Actions	●			
Evaluation & Effects	●	●	●	●
Integration of transport and land use planning		●		●
Infrastructure, Safety, Service	●	●	●	●
Competitiveness		●	●	

The first domain is related to cycling planning i.e. national and local strategies and local plans. The second one is focused on cycling facilities: network design according to current and predicted demand, intersection control, equipment on cycling paths, signalization i.e. road markings, traffic signs and traffic lights. The fourth domain deals with safety, i.e. campaigns, training and education. The fifth includes cycling integration: bike sharing, bikes on public transport vehicles, bike parking provision near bus stops and bike transport by taxi. The next domain is related to the participation of various stakeholders when planning and proposing appropriate solutions. The last, seventh domain is about monitoring in terms of key performance indicators, monitoring mechanism and reporting.

As we emphasized earlier the second task within this phase is to establish proper scoring system. To address this we followed the ladder of development in BYPAD, ADVANCE, [3] and [12], and propose four level scoring system in the following manner:

- Level 1 - Ad-hoc oriented approach: There are no strategies or plans but the need to define them is recognized; modest solutions and minimal performance in all aspects; system failures are solved ad-hoc with minimal engagement; local government bodies are familiar with relevant designing manuals, rule books and guidelines but they do not act upon them as much as necessary; activities in the field of cycling are conducted based solely on the estimate of local authorities‘, whereby users‘ requirements are disregarded; the maintenance is only carried out when a problem evolves and impedes normal functioning of cycling flows; quality is only the result of individual efforts and enthusiasm.

- Level 2 - Isolated approach: Certain solutions are applied to some extent, whereby the positive effect is evident; sometimes local government bodies evaluate current state and keep notes; sometimes there is a contact with certain stakeholders in order to determine which activities are need; certain implementation and maintenance actions are carried out regularly and in accordance with valid rule books; there is a cycling policy but it is not integrated into urban mobility policy neither into separate fields like land use, health and environment, etc.

- Level 3 - System oriented approach: Various solutions implemented in all aspects along with obvious positive results; Current condition inspection is carried out periodically and statistics are regularly collected; strategies and plans are developed on the basis of current user needs and they are available to the public; maintenance inspection includes criteria for cycling facilities; cycling is integrated into the general mobility policy; there is a cooperation with stakeholders in order to determine what cycling facilities are desirable; in many cases construction/implementation of road markings, signalization and lighting is carried out upon valid rule books.

- Level 4 - Integrated approach: Innovative solutions with systematic approach to monitoring; strategies and plans are integrated into local administration documents and measures are implemented; all designing, construction and maintenance works are conducted in line with the needs of cyclists, as well as the needs of all other road users; cycling flow counting and other field data are regularly collected and uploaded in cycling management system; user satisfaction level is investigated regularly; regular information, knowledge and experience sharing among internal and external actors exists.

The proposed scoring system is generic (like in BYPAD and ADVANCE) meaning that it applies to all seven domains. This is important because it allows the scorecard to be easily updated with new modules or KPI. In line is another important feature, also common in EU schemes - to have an NA option for an answer.

The ladder of development is suitable since it directly guides decision makers in terms what to do in order to climb up to the next adjacent level of quality. However one must be aware that there is a far extent of criticism regarding this approach. Some scholars that discussed it in terms of cross-country evaluation, argue that it cannot be straightforwardly translated from developed to developing nations [25]. For this reason we offered an adapted characterization of levels, compared to original ones in ADVANCE and BYPAD.

Two task in this phase 1) modules and 2) levels are finished after they are crossed with findings on best practice examples tracked in phase 2. Following the ADVANCE and [8, 12] each module should be assigned with links to best practices i.e. those which reflect level 4. For example, regarding integration of cycling in transport system good practice example is solution in Thessaloniki (Greece). To *put this good practice into practice*, representatives of different authorities who are very familiar with the urban planning and the current situation should cooperate and transfer their experience [26], e.g. within CIVITAS network. Regarding Target groups & Partnerships an example of good practice is the city of Geneva. As part of the CIVITAS project, the city of Geneva has worked with private companies, international organizations and public administrations to promote cycling policy, as well as with local associations and public administrations in implementing the adopted measures [27]. Also Geneva is an example of good practice regarding promote cycling policies and adopted measures. Integrating good practice exemplars in evaluation scheme is two folded. First it makes easier for respondents to appraise the level of success once they are introduced what top achievement entails (level 4). On the other hand, it gives valuable signposts for drafting improvement plan.

4.4. M&E - putting scorecard into practice

This phase is about putting Scoreboard into practice. It is very important to make this a regular activity (preferably on annual basis) so that authorities are aware of current state of play at any time. This allows to continuously track progress along all modules, which makes TQM and MM effects become both visible and measurable. Also it is desirable to have simultaneous checks in several cities, compare results and set a network for exchanging ideas for improvements both in regards to city cycling policy and the scoreboard itself.

This phase is performed by the auditor which is an external expert (preferably licensed as auditor according to ISO 9000 and familiar with CEN‘s Code [7]). He is entitled to gather opinions from all work group members and consolidate them into a single database. This database could contain some additional data (apart from the one from scorecard) like data on traffic signalization elements for cyclists, as well as cycling flow control, etc. Furthermore, these databases could be useful for priority identification, classification and determination in the future regarding installing, maintaining or replacing traffic signs, monitoring cyclist traffic accident trend line, noting users‘ complaints or requests etc.

After filling out the scorecard by each group member a series of confrontation/consensus meetings should be launched. They proceed until a consensus on the current quality levels is reached for each domain.

4.5. Obtaining Cycling improvement plan

Completed scorecard is just a mean towards the final outcome - cycling improvement plan. This (preferably annual) plan is derived from the scoreboard results and depicted best practice examples in phase two. Plan is drafted by work group coordinator and delivered to all work group members who then discuss priorities and actions. Inter alia, the feasibility of those actions, as well as the time frame for their implementation, is considered. All comments are taken into account when creating the final plan defining action realisation dynamic. Accordingly, the final version of the implementation plan is derived after a series of confrontation/consensus meetings.

5. CONCLUSION

In this paper we have addressed the question of why and how the quality management can support urban mobility planning. We focused on EU experience in devising appropriate monitoring and evaluation schemes that can help local authorities to assess current state of play and devise improvement plans in the field of mobility management. Using cycling policy as an important domain of urban mobility shift, we have proposed a framework for this kind of assessment in Serbia. In general terms this work explains how to exploit latecomer‘s advantage in urban mobility monitoring and evaluation.

However much is to be done to come up with complete QM or TQM approach. One of the issues of interest are aspects that should be audited and/or self-assessed in case the city has not yet adopted the SUMP. The central question is how to translate urban mobility goals scattered over various documents into evaluation criteria.

Along comes another topic of interest - linking measurement to strategy. Within the approach proposed in this paper this means to consider moving from scorecard to balanced scorecard (BSC) under the umbrella of total quality management. This is the subject of our future work.

ACKNOWLEDGMENT

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Contact address:
Marijana Petrović
University of Belgrade
Faculty of Transport and Traffic Engineering
11000 Belgrade
Vojvode Stepe 305
E-mail: marijanap@sf.bg.ac.rs

UNIVERSITY OF NIS FACULTY OF MECHANICAL ENGINEERING

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NEW CONCEPT OF TRAIN AND RAILWAY INFRASTRUCTURE MAINTENANCE

Dušan STAMENKOVIĆ[1]
Milan BANIĆ[1]
Aleksandar MILTENOVIĆ[1]
Miloš SIMONOVIĆ[1]

[1)] *Faculty of Mechanical Engineering, University of Niš*

Abstract

It is necessary to improve the maintenance of railway in order to increase the safety of railway transport. There are different possibilities of inspection the condition of railway vehicle's and infrastructure's equipment, like ultrasonic and eddy-current inspection, measurement of acoustic emission, measuring of the vehicle vibrations in running condition, and other. Measuring equipment can be installed in vehicle (on-board diagnostic) or near the track (wayside detectors). Condition monitoring of railway track can be performed by using in-service vehicles, and condition monitoring of railway vehicles can be performed by wayside detection. Diagnostic data processing are very important and new concept of maintenance is based on implement decision making of maintenance activity based on real time railway condition information.

Key words: *Railway, maintenance, condition monitoring, train, railway infrastructure.*

1 INTRODUCTION)

Railway traffic is constantly improved and developed: requirements for higher speeds, more powerful locomotives, increase of rail cars capacity, greater reliability and availability, increase of security and so on. This caused an increase in axle load, resulting in the increased load on the rails and all elements on the railway track. The maintenance of rolling stock and infrastructure has also been changed, substantially. Condition-based maintenance is current concept of the railway maintenance.

Many researches in area of railway condition monitoring are performed today. Authors in [1] explain some practical applications of diagnostic systems and types of sensors used for monitoring specific parameters are compared.

Stationary diagnostic systems that are installed inside the workshops can be used for the inspection of the certain assemblies of the vehicles, which are excluded from the traffic. But wayside systems that are installed outside, on the railway infrastructure near the track, can be used for the inspection of the railway vehicles in service [2]. Author described the wayside condition monitoring technologies.

Based on performed research [3] authors determine that the most effective maintenance of railway vehicles is inspection without interrupting vehicle service and they present the measuring of locomotive vibration in running condition that can provide useful data of vehicle components state but also data of track state.

Tsunashima et al [4] propose the very useful approach of railway track condition monitoring using in-service vehicle. This track-condition-monitoring system is based on measuring the vertical and lateral acceleration of the car body, as well as measuring noise in vehicle cabin. The field tests were conducted in Japan Railway and results showed that the condition monitoring of railway track using the developed probe system provide the useful information for condition-based maintenance.

Failures of axle bearings are often the cause of train derailment. The paper [5] describes onboard acoustic emission measurements carried out on freight wagons with purposely damaged axle bearings. Acoustic emission signal envelope analysis has been applied as a means of tool to detect and evaluate the damage in the bearings.

Authors in [6] show the statistics data on immobilization of freight cars on the Serbian Railways, and according that they present reasons for reject in the shift traffic stations, indicate that the defects have to be detected even during the train running. Freight car maintenance can be performed more efficient using wayside detection systems and they are much more reasonable in terms of expenses.

The novel approach to railway condition monitoring is presented in the papers [7,9]. The papers discuss integrated monitoring of the wider railway system, with particular reference to Alstom's systems, including remote monitoring and automated depot inspections of railway vehicles.

The paper [8] surveys wireless sensors network technology for monitoring in the railway industry for analyzing systems, structures, vehicles, and machinery. In recent years sensor devices have become cheaper and this has led to a rapid expansion in condition monitoring of systems using sensors This paper focuses on practical engineering solutions, which sensor devices are used and their applications and describes the sensor configurations and network topologies.

In this paper, the continuous monitoring of railway vehicles and railway infrastructure as the most important parts of the railway maintenance is analyzed.

2 RAILWAY CONDITION MONITORING

Traditional railway industry has applied preventive maintenance based on time or running distance. According the periodic information about assets condition it is hard to identify faults in time and undertake the appropriately maintenance activities. Therefore it is needed to make the transition from preventive to predictive maintenance.

The basic maintenance of railway vehicles comprises the interventions implemented on daily basis before, during and after the performed transport and it is called the permanent monitoring. The control inspections of vehicles are performed with the scope that is determined by the running distance. With the new types of railway vehicles, which are equipped with modern diagnostic systems, maintenance interventions are planned on the basis of processing of the signal from the sensors.

There are on-board diagnostic systems which are placed in vehicles and stationary diagnostic systems which are placed on the track or near the track. On-board systems are installed on the vehicles and they are used for vehicle's components continuous monitoring in regular service. On-board diagnostic system is often aimed at monitoring vehicle dynamics using the accelerometers and in that way it is possible to collect date about the state of vehicle suspension and wheel during train running, but also to collect date about the state of track. Wayside detection systems (stationary diagnostic systems) are used for a casual-periodic inspection of rolling stock and these are installed directly on the track or very near track. Condition monitoring of vehicles is performed in time of regular service, without stopping. There are different types of wayside detectors as: hot bearing detectors, wheel impact load detectors, overload and imbalanced load detectors, truck performance detectors, wheel profile detectors, hot wheel detectors, acoustic bearing detectors, etc.
Figure 1 shows some of typical placements of sensors on vehicles and track [1] that are focused on the wheel/rail contact and vehicle running gear.

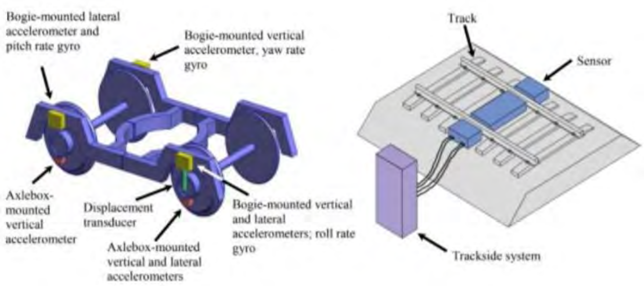

Fig. 1 *Typical placements of sensors on vehicle and track [1]*

Service life and availability of railway vehicles and railway infrastructure assets greatly depend on their maintenance. The permanent monitoring of assets condition is the basic maintenance activity and it is essential for the safety of railway traffic.
The quality of service life of rolling stock depends primarily on the quality of production, and components that are built into it. However, an important role has the condition of exploitation and maintenance of the vehicles. If the vehicles during operation are not exposed to the overload and extreme conditions, and if the maintenance is well-timed and efficient, the vehicle service life will be longer. It is similar in case of railway infrastructure.
The most important reason for railway monitoring condition is to avoid accidents, as a derailment, which is very costly and may cause injuries.

3 STATIONARY AND ON-BOARD DIAGNISTIC SYSTEMS

From the point of rolling stock reliability and safety of rail service, the most important assemblies, in addition to the brake system, are wheel sets, particularly the wheels. Due to the damage of the wheels derailment of the train can appear, and the early detection of wheel defects is essential for the safety. Most of the condition-monitoring systems (wayside and on-board detectors) for railway vehicles are focused on the wheel and bogies. The wheel-rail interface is one of the most important parameters in the vehicles operating condition.
There are many defects that can occur on vehicle running gear, but as the basic ones, can be specified:

- damage of the wheel flange,
- overheating of wheels due to normal braking or due to faults of the brakes (usually due to blocking),
- overheating of the brake discs on vehicles with disc brakes due to the reasons above,
- overheating of the axle bearings,
- other damages on wheel sets (wheel damages, excessive wear and changes of geometric measures, cracking of axles and wheels, etc).

The highest number of damages on vehicles occurs during movement, and it can be determined exactly in dynamic conditions and not in stationary condition. Stationary diagnostic systems, installed on the line represent the measuring stations for railway vehicle dynamic control, in other words, the inspection of vehicles, within the regular operation, is performed without stopping.
Wayside detection systems installed along the line usually have the aim in the following [2]:

- discovering the parts of the car coming out of the loading gauge;
- establishing overheating axle bearings and heating of the wheel;
- establishing the slipping of the wheel;
- acoustic detection of bearing– failures;
- monitoring the vehicle performance;
- wheel condition monitoring;
- vehicle video monitoring.

The control/measurement of the train gauge is performed using the measurement system, based on a laser distance measurement, combined with high frequency scanning (Figure 2). This diagnostic system measures the profile of the train in the movement and it can determine the loading gauge in the freight train.

Fig. 2 *System for train gauge control*

Acoustic measurement method application is increasing rapidly. This technology uses the microphones for recording the sound of vehicles passing. Monitoring systems used are mainly related to the shaft bearings, because it is well known that the failures of the bearings make vibrations in frequencies that can be linked to the characteristics of defects. Acoustic detection systems are preventive systems for axle bearing maintenance developed to identify bearings with internal defects in the early stages of failure, prior to catastrophic failure due to increased temperature during operation. System consists of a series of microphones placed near the track that record data about the sound track of each bearing (Figure 3).

***Fig. 3** Acoustic detection system*

The heat radiation from the objects may be detected by infrared cameras. This technology allows recognizing accurately the areas with high or low temperatures. The system (Figure 4) uses thermal imager technology and digital image processing. This system consists of three to four modular scanners covering axle bearings and brake discs.

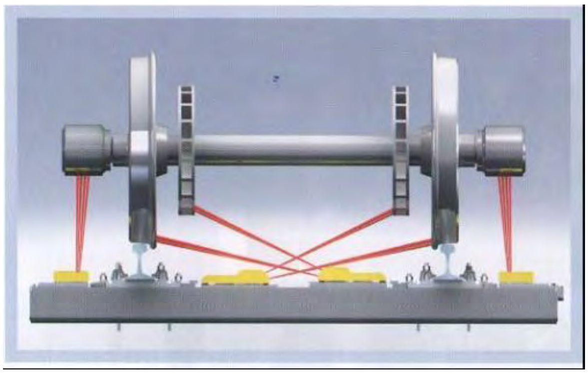

***Fig. 4** System for detection of preheated wheels, bearings and blocked discs*

An example of on-board diagnostic is pantograph condition monitoring using image processing showed in Figure 5.

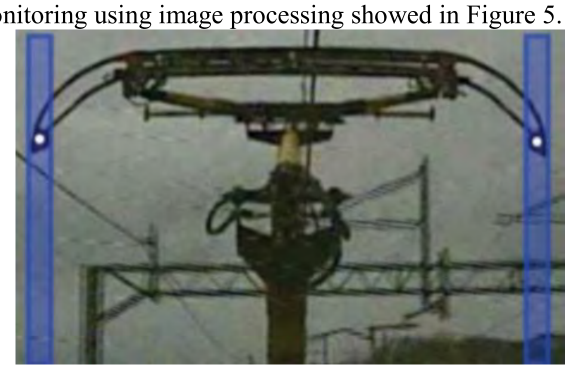

***Fig. 5** Pantograph condition monitoring*

4 DIAGNOSTIC DATE PROCESSING

Diagnostic data processing is very important part of train and railway infrastructure maintenance. The impact of a recorded/measured defect on the railway can be analyzed by processing of captured data and availability of historical data in the system. The processing of measured data should include the dynamic nature of the load and the impacts of the rolling stock defects on the track. Degradation of the track over time can be predicted due to the evolution of the measured load parameters.

Some companies, like Alstom, were developed advanced wayside and on-board monitoring systems. Alstom have developed a wayside monitoring system called “HealthHub” (Figure 6). It is installed at depot on frequently used sections of track and provides automated inspection of various elements of the rolling stock as it passes. Equipments currently included in the automated inspection are pantograph, wheels brake pads, underframe, panels and covers [7].

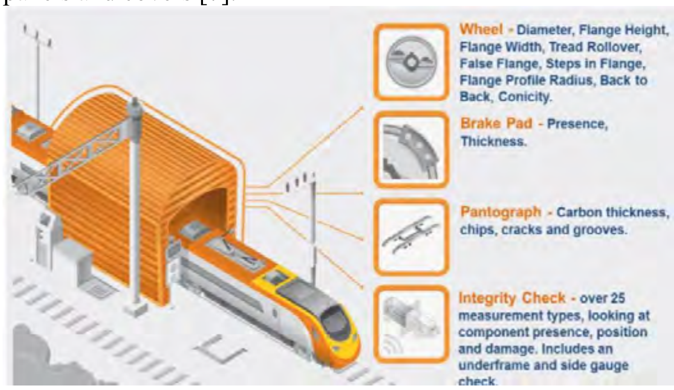

***Fig. 6** “HealthHub” wayside monitoring system [9]*

Collating data from train on-board monitoring and HealthHub enables more efficient maintenance and repair activities. Use of trending and more frequent automated depot inspection can also be used to support the increase of inspection intervals and extension of component life.

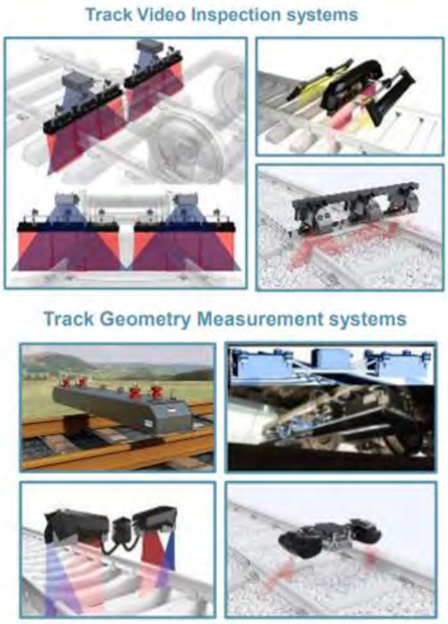

***Fig. 7** Diagnostic systems for monitoring of track [9]*

Alstom have been also developing a system called "TrackTracer", wherein equipment fitted on service trains provides monitoring of the infrastructure. This system currently uses cameras and sensors to monitor overhead line and rail condition, geometry and quality (Figure 7). This will provide Network Rail with frequent monitoring of the line from multiple fleets in regular service [7].
Advanced processing system so-called Wireless Sensor Network [8] is described in further text.
Figure 8. shows a typical wireless sensor network setup for railway condition monitoring. Sensor devices are mounted on places i.e. objects being monitored such as track, bridges or trains. One or more sensors are mounted on a sensor board (node). The sensor nodes communicate with the base station using a wireless transmission protocol. The base station collates data and transmits it to the control center server possibly through satellite or GPRS.

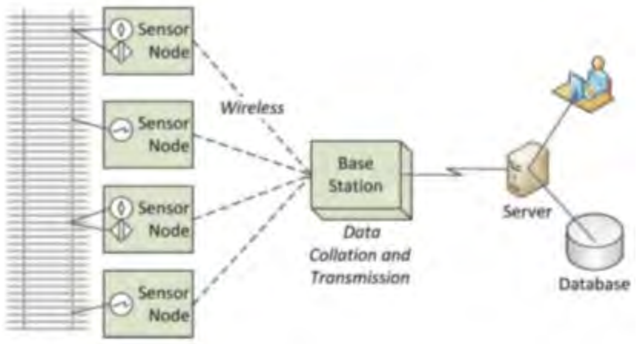

Fig. 8 *Typical wireless networks for condition monitoring [8]*

The base station controls the sensor nodes and transmits data further to a remote server. The sensor nodes use short-range communication such as Wi-Fi or Bluetooth to transmit data to the base station. The base station uses long range communication such as GPRS or satellite to transmit collated data back to a server at a control center. It has a more powerful processor and more memory than the sensor nodes to allow it to collate data from multiple sensors.
Wireless sensor network monitoring provides continuous, real-time and autonomous data acquisition. This system increases frequency of monitoring compared with manual inspection; improves data accessibility, data management, and data use compared with non-networked systems. All data can be collected and processed centrally; the ability to combine data from a wide variety of sensors; intelligent analysis of data to "predict and prevent" events using intelligent algorithms; the ability to turn data into information about the status of important structures, infrastructure and assets; and, a global data view that allows trending information to be determined where degradation is happening slowly over a relatively long period of time [8].
Wireless sensor network monitoring can be used to prevent failures, to estimate maintenance requirements, to minimize downtime and according that, this system increases the traffic safety.

5 CONCLUSION

On the base of electronics development, sensor and computer technology, on-board diagnostics and stationary diagnostics were introduced. On-board systems are installed in the vehicle and they are used for continuous monitoring of devices in operation. Stationary diagnostic systems are used for casual-periodic safety inspections of railway vehicles and they are installed along the line. The modern diagnostic systems have significantly improved the constant inspection of railway vehicles and infrastructure and in that way increased the effectiveness of condition-based maintenance. In addition, it is essential that measured data are recorded and systematized in order to make correct decision about the implementation of maintenance activity.
Improvement of railway condition monitoring consists of:
- Development of methods and sensors for reliable measuring of appropriate parameters
- Determination of reliable system for collecting, analyzing and processing measured data

The new concept of railway maintenance is based on the reliable diagnostics and processing of systematized diagnostic data.

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Contact address:
Dušan Stamenković
University of Niš, Faculty of Mechanical Engineering
18000 Niš, A. Medvedeva 14
E-mail: dusan.stamenkovic@masfak.ni.ac.rs

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THE INFLUENCE OF MIRRORS POSITION ON THE DRIVER VISUAL FIELD

Nadica STOJANOVIĆ[1]
Ivan GRUJIĆ[1]
Jovan DORIĆ[2]
Saša VASILJEVIĆ[3]
Bojana BOŠKOVIĆ[4]

[1] *University of Kragujevac, Faculty of Engineering*
[2] *University of Novi Sad, Faculty of Technical Sciences*
[3] *High Technical School of Professional Studies, Kragujevac*
[4] *College of Technical and Mechanical Engineering Trstenik*

Abstract

In order to reduce traffic accidents, the automotive manufactures have very hard task, where is necessary to design such vehicle, that by its design, in no one case will not cause that driver not notice other participants in traffic. However, drivers must to set up the mirrors how is defined by standards. The aim of this paper is to show, how much drivers respect defined standards, more accurate, what they have learned at their first driving classes. Besides that, it has been shown the driver visual field by applying the CATIA software package, module RAMSIS, in respect to the driver height. The important conclusion of this paper is that it is only necessary to modify the position of the inside central mirror by entrance of other driver, which by anthropometric characteristics is far different than previous. In order of further improvement and reduction of traffic accidents, it is necessary to equip vehicle with cameras and sensors, which will warn the driver about critical situation.

Key words: *traffic accident, design, visual field, CATIA, RAMSIS, anthropometric characteristics.*

1 INTRODUCTION

The task of the driver is not simple at all and it demands high concentration, where is necessary to keep track all events in the traffic. Visual information's are playing very important role during the driving [1], so constant tracking of all events around the vehicle, play important role in the safety driving process.

By the conclusions from the research of Bao and Boyle older and younger drivers are checking the rear-view mirror significantly less in respect to middle-aged drivers [2].
The visual field is one of key factors that effect on the traffic safety, and causes for visual field reducing, is investigated by Quigley et al [3], one of the reasons for the visual field reducing is the increasing of the A-pillar thickness. The same conclusions had Cho and Han [4], besides that, they have conducted research in order of the visual field increasing. Besides the vehicle that is designed as such to reduce the mentioned problem to the minimum, one of the reasons for bad visibility is the driver itself. On this can affect, badly adjusted seat, as well as the badly adjusted mirrors [5], and because of this, blind spots will appear. A blind spot in a vehicle is an area around the vehicle that cannot be directly observed by the driver while at the controls. Blind spots exist in a wide range of vehicles depending on the size and technological solutions of the vehicle.
The car manufacturers, during the manufacturing must to respect all regulations, in order to provide safe driving. The regulations that are defining the mirrors montage are
ECE 46 and 81 [6]. By entering in the vehicle, the driver is obligated to adjust the seat, in order to be comfortably, and after that he must to adjust mirrors, such to see the environment around the vehicle, as best is possible. Unfortunately, it can be noticed that on some vehicles some of mirrors are missing, or in some cases are closed.
It exists two ways for mirrors adjusting, and that:

1. Typical rear-view mirror configuration (Figure 1, left) and
2. Optimal rear-view mirror configuration (Figure 1, right).

The first way represents the mirrors adjusting, on the way how is learned on the driving classes, while the other way, represent the idea for blind spots reducing to the minimum.

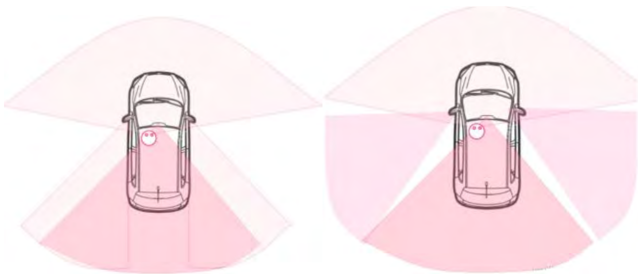

Fig. 1 *the driver visual field in respect of mirrors adjusting [7]*

However, it exists elimination of side mirror blind sports with George Platzer's Methodology. In 1995, George Platzer published a Society of Automotive Engineers paper that claimed that a particular side view mirror adjustment that can eliminate any blind spot that can hide an automobile [8]. He claimed that the primary reason for side mirror blind spots exist is because most drivers adjust them as defined by the first method. He has concluded, that by adjusting mirrors how is defined in second case, blind spots will not appear.
The problem that can be caused by badly adjusted mirrors is traffic accident. The most vulnerable group in the traffic are two wheelers. Drivers of two wheelers, by the construction are smaller, and they can pass through densely traffic very easily, which is characteristic for great towns. They are using

this possibility very often, which is not smart at all. They are very often in the situation, where other participants can't see them, and because of this they are being harmed. In the moment of the traffic accident, the 40% of drivers, didn't saw the two wheelers in the mirror [9].
The aim of the paper is based on the analysis of driver's mirrors usage, more accurate analysis of driver's habits, which is investigated by a survey. It will be given the comparison of the visual field for respondents 1 and 2, where mirrors are adjusted according to the respondent 1. The respondent 2 is different from respondent 1 physically, and mirrors have maintained the adjustment from previous respondent. By applying the software package CATIA, RAMSIS module, it will be given the comparison between visual fields of both respondents.

2 DRIVERS HABITS

In order to show, how drivers really are and which are their habits, the anonymous survey has been performed, on the territory of city of Kragujevac. The survey is conducted for 106 respondents, where 67% were males. The respondents are separated by age groups, shown in Table 1. It can be seen that the most respondents are in ages from 18-25, while respondents over the 48 ages were not participated in the survey.

Table 1 Age population of respondents

Age group	Percentage share
18-25	60%
26-32	23%
33-40	15%
41-47	2%
+48	0%

Questions used in the survey, are questions from driving classes. The 95% of respondents have been told that the adjusting of a good position on the driver place influence on the traffic safety. On the question „do you adjust mirrors when you enter in the vehicle that somebody else drived before you" the 89% of respondents, answered that adjust. However, the 82% have confiremd that adjust.
In the survey has been included the question, where drivers should rate, how much they are tracking the traffic events in the mirrors, shown in Table 2. The most of them 36% have told, that they are tracking the traffic events in the mirrors from 81-99%. The respondents who rated themselves as such, are respondents that belong to the age group from 18-32 years. The respondent that have told that are tracking the traffic events from 0-20%, are respondents from the age group 18-25 years. While the respondents who rated themselves from 21-40% are from the age group from 33-40 years, which is for worrying. Those are mature peoples, which have family, and besides that, they are not taking care about themselves.

Some situations in traffic can be unpredictable and critical, such is trespassing from one lane to another. Those are the situations where traffic accidents can happen, and one of the reasons can be the badly adjusted mirrors, where 34% of the respondents have told that they were exposed to such situation. However, habits of drivers are very interest, so 30% of the respondents told, that they are not using mirrors for traffic events tracking.

Table 2 The grade of respondents about themselves

The grade	Percentage share
0-20%	1%
21-40%	3%
41-60%	13%
61-80%	28%
81-99%	36%
100%	19%

Besides the questions that are showing driver's habits, in the survey were included other questions, with purpose to check the respondent's knowledge, which they have obtained during driving classes, and by experience. So, there was included three questions for knowledge checking, shown in Table 3. The answers are shown in Table 3, and it can be seen that their knowledge is not on the satisfying level.

Table 3 Drivers knowledge checking

The inside mirror should provide:	
Observing the passengers on the rear seat	2%
Spotting the vehicles that are at the back of the vehicle	98%
The outer mirror should provide:	
The visualization of the road and of the rear left tyre	18%
The visualization of the road and of participants from the other lane	24%
The visualization of the road, participants from the other lane and the quarter of the vehicle	58%
The outer right mirror:	
The visualization of the road/roadside and of the rear right tyre	22%
The visualization of the road/roadside and of participants from the other lane	22%
The visualization of the road/roadside, participants from the other lane and the quarter of the vehicle	56%

On the conducted survey basis, it is noticed that driver's habits are very complex, and that it should conduct educative courses in order of their awareness improvement. However, it can be said that the survey, had and positive effect, because that at the end of the survey, the respondents asked questions in order to improve their knowledge.

3 DETERMINATION OF THE VISUAL FIELD IN THE PASSENGER CAR OF M1 CATEGORY

Today experiments can be replaced with numerical analyses, by starting from the analyses of stresses that occur in mechanical parts, to the determination of the driver visual field. It is created the 3D model of the vehicle, more accurate the model of passenger car (M1), for which the body shape is defined by standard SRPS ISO3833:2005, it is limousine AA [6], Figure 2.

Fig. 2 *3D model of the vehicle*

In this paper, the analysis is performed by using the CATIA software package, RAMIS module.
The research is performed for two respondents that by anthropometry are very different one from another. The anthropometric dimensions that are playing important role in the visual field determination are given in Table 4. In order for beater understanding of given dimensions, the Figure 3 is given. At first it is performed the analysis with the respondent 1, where the mirrors are adjusted how is convenient for him. After that, the visual field determination was performed for the respondent 2, but with the same position of mirrors. The seat position also wasn't changed for the respondent 2.

Table 4 The respondent anthropometry [10]

	Respondent 1	Respondent 2
Body height, mm	1771	1649
Siting height (*a*), mm	927	871
Knee height sitting (*b*), mm	563	522
Buttock knee length (*c*), mm	616	582
Gender	Male	

Fig. 3 *Dimensions for sitting posture [11]*

First it is performed comparison of the visual field for both respondents, when they are looking in the inside mirror. The mirror is adjusted for the respondent 1. The visual field of the respondent 1, when he is looking in the inside mirror, it is shown on Figure 4. It can be noticed that the visual field of the respondent 2 is much narrowed (Figure 5). The red line (Figure 5 - upper) it is showing that everything that is over this line, the respondent 2 cannot see. More accurate, the half of the surface that he can see in the inside mirror is the roof of the vehicle. So, it is necessary to adjust the mirror for the respondent 2, in order to improve his visual field, more accurate to see more widely.

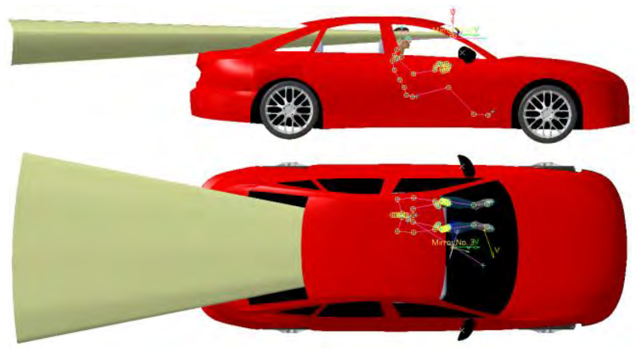

Fig. 4 *The visual field in the inside mirror – the respondent 1*

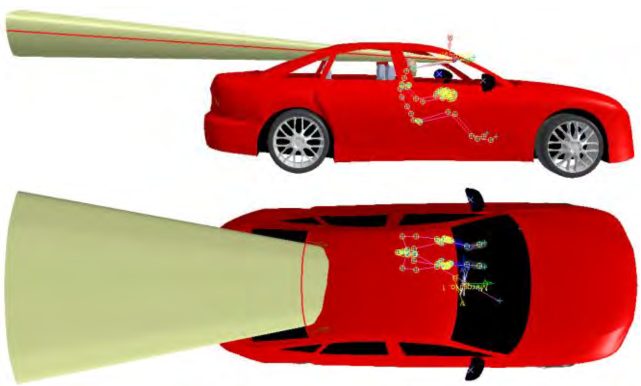

Fig. 5 *The visual field in the inside mirror – the respondent 2*

As in the case for the inside mirror, as well as the left mirror is not adjusted for the respondent 2. The left mirror is in the position that corresponds to the respondent 1, Figure 6. There not exist many differences in the visual field of the respondent 1 and the respondent 2, Figure 7. It can be concluded, that if the respondent 2 do not adjust left mirror, the traffic safety will not be disturbed because of this reason.

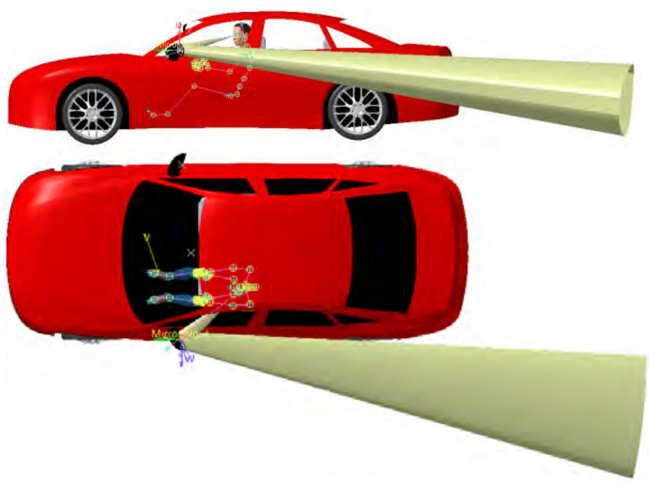

Fig. 6 *The visual field in the left mirror – the respondent 1*

The same conditions as in the previous two cases are defined and for the right mirror. Also it can be noticed, that don't exist important differences between visual fields of the respondent 1 and the respondent 2, Figures 8 and 9. The only difference is in the angle of the visual field (the surface that is reflected from the mirror surface), for the respondent 2 is less in the respect to the road surface, which in this case means that he will see further than the respondent 1.

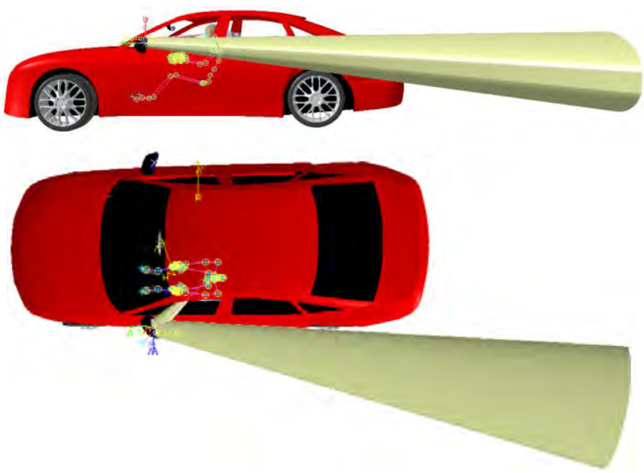

***Fig.** 7 The visual field in the left mirror – the respondent 2*

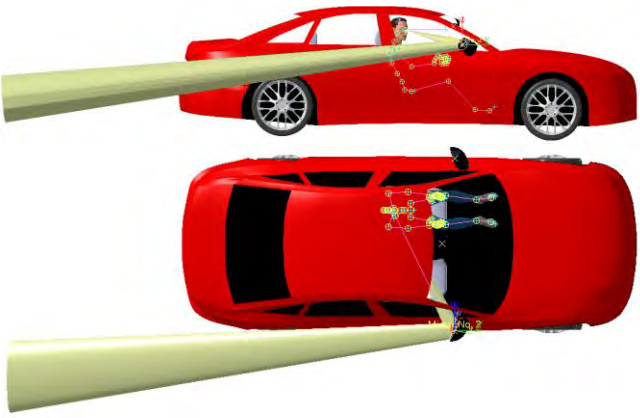

***Fig. 8** The visual field in the right mirror – the respondent 1*

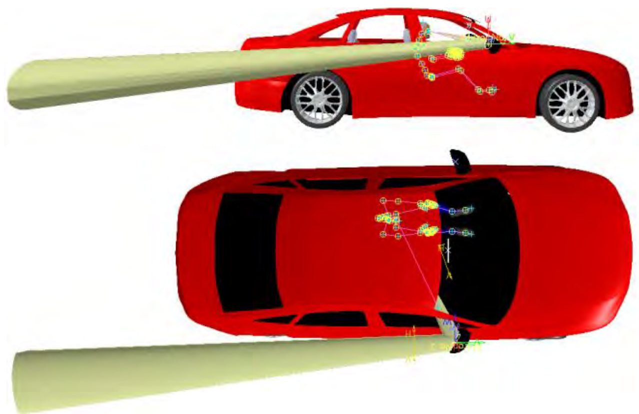

***Fig.** The visual field in the right mirror – the respondent 2*

By entering in the vehicle, the driver is obligated to adjust mirrors in order to improve the visual field from the vehicle. The application of modern system in order of blind spots reducing

4 THE APPLICATION OF MODERN SYSTEM IN ORDER OF BLIND SPOTS REDUCING

However, even in the case, when mirrors are adjusted, even then blind spots exist. In order to increase the traffic safety of all traffic participants, and reducing the blind spots on the vehicle, it exist possibility of cameras mounting on the vehicle, as well as the sensors mounting, which will have the task to warn the driver about the vehicle in critical zone.
By applying (Figure 10) cameras instead mirrors, the air resistance is reduced, more accurate the turbulences that caused by the mirrors are reduced [5].

***Fig. 10** Virtual mirrors [12]*

Also by applying cameras instead mirrors, the higher number of information's can be obtained [13], the only disadvantage of cameras is that by moving the head, cannot be obtained other information's, instead those that are recorded by camera, which is not the case for the mirrors.

Blind spot system contains one sensor at each side of vehicle's end and it provides the vehicle detection in blind spots. One such system provides safe trespassing from one lane to another. If the sensor finds the vehicle in these critical zones, the system will warn the driver with light signalisation (Figure 11), or with sound or vibrating signalisation.

***Fig. 11** Blind spot sensor Lights up [14, 15]*

The application of the new technologies on the vehicle must to satisfy next:

- Good colour and contrast reproduction, minimisation of artefacts;
- Quick adaption to changes in ambient brightness;
- Representation with no time delay;
- Detection and immediate display of image losses or, even better, ensuring that image losses do not occur and
- Frost and condensation protection.

5 CONCLUSION

Habits of drivers are very complex, which proves the conducted survey. Respondents habits should change, and to improve their consciousness, by educative courses, emissions and commercials on the television and radio. Besides that, it can be said that the survey had and positive effect on respondents, where they after survey have asked for correct answers on some questions, and besides that many of them was said that the wasn't think in such way.

It is investigated the driver visual field for two respondents, that are very different by anthropometric characteristics, and it is concluded that it is necessary the adjustment of the inside mirror. While the adjustment of outside mirrors is not necessary, because the visual field is almost unchanged between respondents, which means that the traffic safety is not disturbed.

However, sometime, it is very hard to change people's habits and because of this, vehicles have implemented sensors, which have the task to warn the driver about critical situation. One more reason for sensors application is to detect the vehicle, which is in the blind spot, and to warn the driver immediately, because during the long-time driving, the driver concentration can fall. By applying new technologies, the traffic accidents will be reduced. So, by using sensors, the vehicle in blind spot will be detected, because how is concluded till now, the mirrors cannot provide the visual field that cover 360° around the vehicle.

Future researches should base on detail survey, where will be included, how long respondents are drivers, the degree of education, employment. Besides that, it should investigate if habits of drivers are changing when it has passengers in respect when he is alone in the car. Besides that, the determination of the driver visual field should take into the consideration the wider population, as well as vehicles that are by body shape different one from another. Also, it should include the woman population in the analysis.

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Contact address:
Ivan Grujić
University of Kragujevac
Faculty of Engineering
34000 Kragujevac
6 Sestre Janjić Str.
E-mail: ivan.grujic@kg.ac.rs

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TURBOFAN ENGINE SHOP VISIT MANAGEMENT

Branimir STOJILJKOVIĆ[1]
Ljubiša VASOV[1]
Olja ČOKORILO[1]

[1]University of Belgrade
Faculty of Transport and Traffic Engineering
Department of Air Transport and Traffic
Division of Aircraft

Abstract

Due to high costs and safety issues, turbofan engine maintenance is of central importance to aircraft engine operators. Operating experience indicates that the cost of engine operation may be optimized by extending the cycles between shop visits. Shop visit management and workscope optimization is crucial for achieving lower engine maintenance costs. The analysis of the type and extent of the workscope to be performed at several subsequent shop visits is carried out in this paper on the case study for the CFM56-3 turbofan engine. The results confirm the possibility of significant cost savings by applying the appropriate workscope optimization criteria.

Key words: *turbofan engine, maintenance, shop visit, workscope, costs.*

1 INTRODUCTION

To systematize aircraft maintenance work, taking into account annual utilization, applied loads and operational impacts on safety and economy, an aircraft is divided into three sections, which have different maintenance programs: airframe, engine/systems, and aircraft components.
In addition to pronounced safety impacts, aircraft engine failures can lead to a decrease in both operational availability and dispatch reliability, generating high maintenance costs. Therefore, it is necessary to pay special attention to aircraft engine maintenance.

Aircraft engine maintenance covers all types of maintenance tasks, carried out during the engine life cycle, in order to ensure safe, reliable and cost-effective engine operation.
In general, aircraft engine maintenance is divided into:

- Line or on-wing maintenance (performed without removing the engine from aircraft), and
- Shop maintenance (carried out in specialized engine overhaul/repair workshops, after the engine removal from aircraft).

Given the fact that engine direct maintenance costs represent the highest cost segment (Figure 1), with 42% share in the direct aircraft maintenance costs [1], special attention must be paid to manage and optimize engine shop visits.

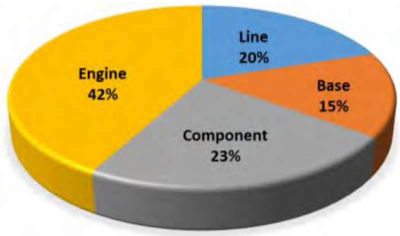

Fig. 1 Direct Maintenance Cost by Segment

Over the engine's service life, there is a need to carefully plan engine removals and make operational decisions on the work to be implemented during engine shop visits (module workscope, replacement of life-limited parts).

2 TURBOFAN ENGINE MAINTENANCE

The high by-pass ratio turbofan engine is the most common type of gas-turbine engine used in civil aviation. During operation, turbofan engines become exposed to the combined effects of various external (ambient atmospheric conditions, altitude, flight speed) and internal factors (operating conditions, thrust setting), which lead to wear of engine parts and change of engine condition.
Various forms of component wear (erosion, wear, corrosion, material fatigue, other types of damage), caused by the complex action of mechanical, thermal and chemical influencing factors, lead to changes in the design characteristics of the components, lower the efficiency of engine components, resulting with engine performance deterioration. Besides, experience confirms the fact that wear and tear on mechanical parts can cause certain types of failures (sudden failures, material fatigue failures) which have a direct adverse impact on operating safety.
Aircraft engine maintenance implies all the work that must be performed on-wing, to keep the engine airworthy, and in the engine shop, to bring the engine back into the airworthy condition [2]. The airworthiness of the engine is its ability to reliably and safely carry out the operation for which the engine was designed.
The Civil Aviation Authorities (CAA) recognize three primary maintenance processes:

- Hard Time (HT) is a primary maintenance process under which an item must be removed from service at or before a previously specified time (expressed as the number of operating flight hours, flight cycles, calendar time, etc.).
- On-Condition (OC) is a primary maintenance process that requires periodical inspections or tests of items to determine their continued serviceability. Corrective action is taken when required by item condition.

- Condition Monitoring (CM) is a primary maintenance process under which data on the whole population of specified items in service is collected and analyzed to assess their behaviour and take corrective action to modify the item or maintenance program, if and when necessary.

HT and OC are preventive maintenance processes, aimed at removing the item before failure occurs, while CM is a corrective maintenance process, which allows failures to occur. The failure modes of condition monitored items are considered not to have a direct adverse effect on operating safety.

Most turbofan engine parts are subject to control by the OC maintenance process, except for the critical engine parts, i.e. life-limited parts, on which HT maintenance process applies. CM applies throughout the engine as a secondary maintenance process. It ensures engine removal from aircraft before failure occurs, based on the continuous monitoring of various engine operating parameters, through the practical application of the Engine Condition Monitoring (ECM) program.

Since engine failures can have a direct adverse effect on operational safety, aircraft engine maintenance is based on the condition-based preventive maintenance concept, under which the engine is subject to control by the primary maintenance processes (HT, OC, and CM). The primary maintenance processes are interrelated and equally important to engine maintenance program. In most cases, the OC process dictates engine removals, but all three primary maintenance processes are equally important, and the priority of their application depends only on the type of event that occurs first [3].

Observed through the development of turbojet engines and Maintenance Steering Group (MSG) methodology, the application of today's generally accepted concept of the condition based preventative engine maintenance, was preceded by:

- the implementation of engine condition monitoring methods,
- the capacity of maintenance organizations to implement engine condition monitoring programs,
- technological development of the condition diagnostics devices,
- empirical confirmation of differences in the intensities of performance degradation of the major engine modules, and
- the introduction of the modular design of aircraft engines.

2.1. Modular design of turbofan engines

Practice has shown that engine components, which had parts with different service lives, were easier to maintain if there was a possibility of their individual removal from the engine, which led manufacturers to design the engines, divided into independent, interchangeable assemblies, called modules. Engine modules are separate units that can be monitored and maintained (removed, replaced or repaired) individually, as an independent assembly. Figure 2 shows a typical design of the modular constructed turbofan engine.

Major engine modules are the basic subassemblies, over which further maintenance activities can be performed individually, with a minimum level of disassembly of the other modules. Since they are interchangeable, each engine module can be replaced by a spare one, enabling the engine to return to service with minimum delay.

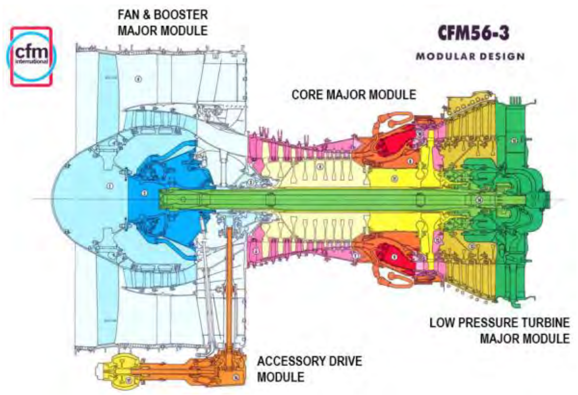

Fig. 2 *Modular design of the CFM56-3 turbofan engine*

The maintenance of modularly designed engines has many advantages:

- instead of disassembling and repairing the whole engine, only the module that requires service becomes repaired,
- engine maintenance personnel can receive technical training per engine modules,
- purchasing a spare module which requires performance restoration more often, rather than buying the entire spare engine, brings significant spares cost savings,
- engine turnaround time is decreased, allowing the flow of air traffic without delays and disturbances, with a smaller number of spare parts,
- the removed module can be further disassembled into mini-modules (shop modules) for life-limited part replacement (the shortest life of the installed part in the replaced module would limit its service life in that case),
- there is a possibility of replacing individual engine modules on-wing, but with caution, since the aircraft on-ground time may be longer than the replacement time of the entire engine.

Assembling the module requires special attention as to install the parts with approximately the same remaining life, to avoid the unnecessary and premature engine removal from service, and to assure full utilization of the life-limited parts' lives. The modular design of aircraft engines has contributed to a reduction of both costs and time required for performing engine maintenance tasks.

2.2. The MSG-3 maintenance methodology

Thanks to the joint effort of experts from the Federal Aviation Administration (FAA), Air Transport Association (ATA), Association of European Airlines (AEA) and aircraft manufacturers from Europe and America, after the publication of the MSG-1 and MSG-2 documents, new procedures for analysis and logical decision making were defined and published by ATA in 1980, in a new document titled „Airline/manufacturer Maintenance Program Development Document", commonly known as the MSG-3 document. The publication of the MSG-3 document has led to significant changes in the process of designing the initial maintenance program since the Reliability Centered Maintenance (RCM) methodology has been used as a basis for its creation.

The MSG-3 approach is oriented towards maintenance tasks, carried out for safety, operational and economic reasons. Maintenance tasks are defined based on a logical diagram for the analysis of the causes and effects of functional failures at the system level, starting from larger assemblies to parts.
With the publication of the MSG-3 document, the period of intensive development of aviation regulation and significant changes in the aircraft maintenance program has been completed. By applying the top-down approach, an aircraft manufacturer creates a list of all on-aircraft replaceable items (system, sub-system, component or part), to identify whether they belong to Maintenance Significant Items (MSIs). For each item from the list, it is necessary to answer the following questions:

- Could failure be undetectable or not likely to be detected by the operating crew during normal duties?
- Could failure affect safety (on ground or in flight)?
- Could failure have a significant operational impact?
- Could failure have a significant economic impact?

An affirmative answer to any of the above questions requires conducting an MSG-3 analysis on a given item, which has two levels. At the first level of analysis, by evaluating each functional failure, the Failure Effect Category (FEC) is determined. At the second level of analysis, by considering all failure causes of each functional failure of the MSI, depending on the FEC category to which the MSI belongs, maintenance tasks are determined.
Maintenance tasks that are applicable to a given FEC category of the MSIs are selected from an established generic list of maintenance tasks, which includes:

- Lubricating/Servicing (LU/SV): maintenance tasks that are applicable to all FEC categories for the purpose of maintaining inherent design capabilities,
- Operational/Visual Check (OP/VC): failure finding tasks that are applicable to items in the hidden functional failure category only, to determine if an item is fulfilling its purpose,
- Inspection/Functional Check (IN/FC): damage, failure or irregularity detecting tasks and quantitative checks to determine the functioning of items within specified limits, that are applicable to all FEC categories,
- Restoration (RS): a repair work necessary to return the item to a specific standard, applicable to all FEC categories,
- Discard (DS): item removal from service at a specified life limit, applicable to all FEC categories,
- Combination of the above tasks: applicable to items in evident or hidden safety FEC categories.

In the final step of the MSG-3 analysis, the Maintenance Working Group (MWG) determines the threshold and interval for performing each scheduled maintenance task that satisfies both the applicability and effectiveness criteria.

3 ENGINE SHOP MAINTENANCE

As noted in the introduction, engine maintenance can be divided into line and shop maintenance. Line maintenance includes the work required to maintain the engine and its systems in an airworthy condition while installed in an aircraft, which can partially restore engine performance. Shop maintenance includes the work required to return the engine to airworthy condition, after its removal from aircraft, which can either partially or fully restore engine performance, to a close level from the beginning of operation.
An engine removal is classified as a shop visit whenever the subsequent engine maintenance, performed prior to re-installation, entails either the separation of pairs of major mating engine flanges or the removal of a disk, hub or spool [4].
The Engine Shop Manual (ESM) contains all the necessary information for performing engine shop maintenance. In addition to this document, engine manufacturers also publish an engine's Workscope Planning Guide (WPG), which contains technical recommendations for optimizing the maintenance performed during each shop visit and details the suggested level of required maintenance on each engine module. One of the following three levels of workscope can be performed on the individual major engine modules, as generally specified by engine manufacturers:

- Minimum workscope level, which refers to the external inspection of the engine module, without its disassembling, to identify if additional levels of the workscope are required,
- Performance workscope level, which requires disassembly of the engine module to perform cost-effective performance restoration,
- Full workscope level, which refers to the overhaul of the engine module. Module overhaul is usually planned and performed when replacement of the life-limited parts is required.

The usual procedure for engine shop maintenance includes the following:

- Incoming engine inspection, consisting of a visual inspection, a borescope inspection and an examination of the magnetic plugs and oil filters for metal scrapings in the oil system,
- Based on the established findings and information received from users (complaints from pilots and mechanics), removal reason, complaints from technical personnel during maintenance and gas path data, an initial program of work on the engine is presented, consisting of disassembling the engine and inspection of the damaged parts,
- Expired life-limited parts are beeing replaced (parts with shorter remaining life can endanger the length of the succeeding engine operating interval, triggering premature engine removal),
- During engine overhaul, works required by service bulletins and modifications are performed,
- After the engine is disassembled, washed and the parts inspected, precise measurements are made to determine their wear and tear, after which a final program of work is given,
- Finishing works include assembling the engine and testing it on a test cell to confirm its condition,
- The engine is sent back to the shop for final assembly and installation on the aircraft.

Modular engine maintenance is performed in organizations that do not have the capability and competence to perform engine repairs. It is only referred to the replacement of engine modules. Repair of parts, balancing of rotary assemblies or machining works that require the use of special tools, are not carried out in an organization which performs modular maintenance.

3.1. The primary causes of engine removals

In parallel with the accumulation of engine operating cycles, life-limited parts consume their lives, and engine performance degradation occurs due to various reasons. Typical causes of engine performance deterioration [5], shown in Figure 3, mainly result from:

- dirt accumulation on blades and vanes,
- a gradual increase in clearance between the compressor and turbine blade tips and the surrounding shroud due to rubbing,
- damaged air seals leakage due to wear and erosion,
- airfoil erosion.

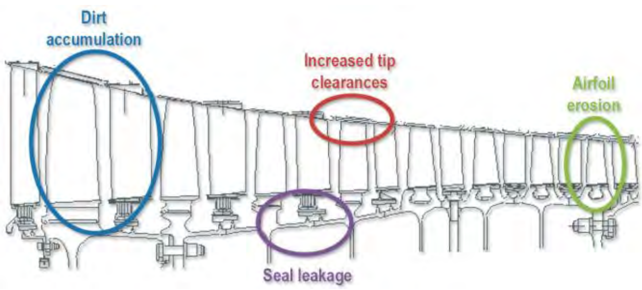

Fig. 3 *Typical engine deterioration mechanisms*

Major engine modules do not contribute equally to the deterioration of engine performance. High Pressure Compressor (HPC) and High Pressure Turbine (HPT) are the main contributors to performance degradation. On some higher bypass ratio turbofan engines, the Low-Pressure Compressor (LPC) may also significantly contribute to performance degradation [6].
Performance restoration of individual engine modules, life-limited parts replacement, and repair of damaged components are performed in specialized engine shops and require the engine removal from the aircraft. The primary causes of engine removals include:

- performance degradation of the major engine modules,
- life-limited parts expiry,
- wear of engine components,
- occurrence of unplanned events (foreign object damages, uncontrolled in-flight shutdowns, bird strikes, etc.).

3.2. Life-limited parts

Engine Life-Limited Parts (LLPs) are rotating parts in a turbine engine that are critical to its integrity. They are mostly composed of disks, spools, shafts and seals, and subject to control by the HT maintenance process. Engine manufacturers specify the service life of each life-limited part in the number of Engine Flight Cycles (EFC) it is allowed to operate. The life span of most LLPs usually varies between 15000-30000 EFC [7]. Each of the engine major modules contains a certain number of LLPs. For example, the CFM56-3 engine has 19 LLPs: three LLPs in the fan and booster module with target lives of 30000 EFC, nine in the core module with target lives of 20000 EFC and seven in the LPT module with target lives of 25000 EFC. Since the CFM56-3 engine can be used at different thrust ratings, the LLP limits mentioned above will be shorter when the engine is used on higher thrust ratings. The previous considerations show that life-limited parts' lives depend on the engine module in which they are installed and on the thrust rating at which the engine is operated.
Life-limited parts' lives can be easily monitored by recording engine utilization. After reaching their approved life limits, life-limited parts must be replaced in the engine shop. The reduction of shop visit costs demands for careful analysis of the planning and management of LLPs replacement.

3.3. The EGT Margin

In order to meet aircraft performance requirements, the engine power management schedule is programmed to provide a constant level of take-off thrust (flat-rated thrust) with increasing Outside Air Temperature (OAT) up to some Corner Point (CP), also named as Flat Rated Temperature (FRT) [8]. The Exhaust Gas Temperature (EGT) margin (Figure 4) is an estimate of the difference between the certified EGT limit (red line) and the projected EGT level of the observed maximum EGT, which would be achieved at take-off with full-rated thrust, under the reference condition [6]. The referenced condition is usually defined by the OAT equal to the FRT (or CP) and by the sea level pressure. CP depends on the engine type and is usually higher than the standard ISA temperature by about +15°C.

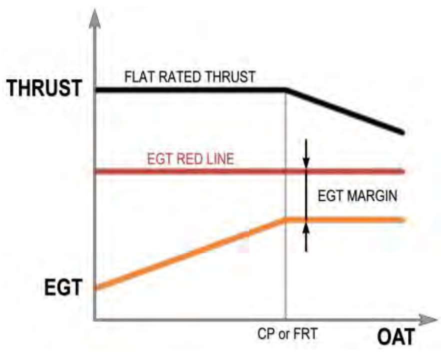

Fig. 4 *Flat-rated trust and EGT margin*

EGT limit is one of the most significant operational limitations of turbofan engines, which is established during the certification of an engine. In the certification process per Federal Aviation Regulations (FAR) and European Union Aviation Safety Agency (EASA) specifications, a series of required tests are performed to demonstrate the structural and operational capability of a given engine type. One of them is the endurance test, which demonstrates the structural integrity of the engine and determines the maximum allowable values of the engine operating parameters:

- Operational speed limitation (N1 limit, N2 limit), and
- Operational EGT limitation (EGT red line).

Wear of engine components and degradation of engine performance can be detected and monitored through the application of engine condition monitoring program. As a result of engine performance deterioration during operation, the EGT increases and the EGT margin decreases, requiring engine removal for performance restoration. Apart from

other removal reasons, an engine can operate on-wing until the EGT margin is consumed.
Therefore, the EGT margin represents one of the most commonly used parameters for monitoring engine performance deterioration, whose monitoring is essential for evaluating the overall engine condition.

3.4. Shop visit costs

An engine's shop Direct Maintenance Costs (DMC) are the result of the performed shop maintenance work on restoring the engine to airworthy condition, and they can be represented by the ratio of the Shop Visit Costs (SVC) to the operated Time On-Wing (TOW):

$$ShopDMC = \frac{SVC}{TOW}$$

Shop visit costs depend on the workscope level applied to the engine modules during shop visit and include direct labour and material expenses induced by shop maintenance.
Shop visit costs usually break down into the labour cost, material replacement cost and parts repair cost. The most significant part of shop visit costs is the material replacement cost, accounting for approximately 60-70% of the cost of a shop visit [7]. The most substantial part of material cost is attributable to the individual HPT stator vanes and rotor blades and to some extent the individual HPC stator vanes and rotor blades. Replacement of life-limited parts during a shop visit will substantially increase the material replacement cost. Direct labour cost will account for approximately 20-30%, while parts repair cost will account for 10-20% of a shop visit cost [7]. The largest share of parts repair cost is also attributable to blades and vanes, since making these parts serviceable requires the application of high technology repairs.Except for the standard division into material and labour costs, it is also pretty common to break down the shop visit costs into performance restoration costs and LLP replacement costs [7]. Performance restoration costs include labour and material expenses for restoring the performance of engine modules, separating the expenditures related to the replacement of life-limited parts.
Table 1 displays the list price of life-limited parts in major engine modules and their approved life limits, according to the data from the 2013 catalogue list prices of life-limited parts for the CFM56-3B1 engine variant, rated at 20,100 lbs of take-off thrust.

Table 1 Life limits and list prices for CFM56-3B1 LLPs

Major Module	*LLP Price*	*No. of LLPs*	*Life Limit*
Fan&Booster	\$460,400	3	30000
Core	\$1,141,020	9	20000
LPT	\$731,360	7	25000
TOTAL	\$2,332,780	19	

Replacement of life-limited parts in particular engine module requires performance restoration of that module, which generates additional labour, material and parts repair costs, leading to the increase of shop visit costs. The high-cost of life-limited parts replacement requires thoughtful decision making on when and what parts should be replaced for achieving the long term shop visit costs reduction.

4 WORKSCOPE DECISION POLICY

The main goal in defining the optimal workscope level during shop visit is to restore the engines performance and to achieve such a condition of the engine, for which the long-term engine direct maintenance costs or the costs per flight hour are minimized. Achieving this goal is often a great challenge, especially when it comes to parts and modules that have different rates of performance degradation.
The usual approach to this problem involves assessing the remaining LLP lives and managing the expiry of time-limited components to coincide with the estimated time of succeeding shop visit. Ideally, an adequate level of workscope would ensure matching the remaining LLP lives with the expected time on-wing, after which the EGT margin becomes fully consumed. For example, if the shortest remaining LLP life equals 8000 cycles at a given shop visit, then the appropriate level of workscope should ensure that the engine has a sufficiently large EGT margin to stay on-wing for 8000 cycles. These 8000 cycles are then often referred to as engine build standard.
The Workscope Planning Guide provides recommendations aimed at improving the EGT margin as well as improving the durability and reliability of the engine. The level of workscope to be performed on an engine inducted into the shop is dependent on the removal cause, time accumulated on the engine modules, observed hardware conditions, trend data at removal, and operator's business goals [9]. Two typical workscope optimization criteria can be identified when planning engine shop maintenance:

- maximum usage of LLPs lives, and
- minimum number of shop visits.

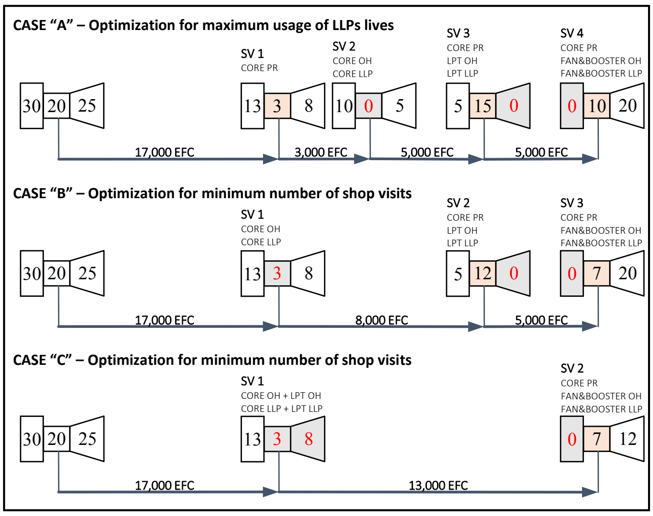

Fig.5 *Workscope optimization criteria*

Figure 5 presents the application of workscope optimization criteria for determining long-term shop visit costs of the CFM56-3B1 engine through the analysis of three different scenarios. All three cases consider the required number of shop visits and the associated shop maintenance costs that result from the applied workscope level, for a total of 30,000 cycles of engine operation. Case "A" outlines the application of the maximum usage of LLPs lives criterion, while cases "B" and "C" refer to the utilization of the minimum number of shop visits workscope optimization criterion.

Obviously, building an engine for maximum utilization of LLPs lives (case “A”) requires frequent engine removals and results with the highest number of shop visits, causing high costs due to performance restoration workscopes. After achieving 17,000 cycles, the 1st shop visit will require core performance restoration (CORE PR), limiting the second on-wing interval to 3,000 cycles due to core overhaul (CORE OH) and LLPs replacement at the 2nd shop visit. The Low Pressure Turbine (LPT) life-limited parts would then limit the third on-wing interval to 5,000 cycles, requiring LPT overhaul (LPT OH) and LLPs replacement, as well as the core performance restoration to be performed at the 3rd shop visit. Finally, the engine would achieve 30,000 cycles after the fourth on-wing interval of 5,000 cycles and require the removal caused by the fan and booster LLPs expiry.

Case “B” analyzes a decision to replace the core LLPs prematurely, after achieving the first on-wing interval of 17,000 cycles. In this way, the second on-wing interval would be extended to 8,000 cycles, and the engine would be removed for 2nd shop visit due to LPT LLPs replacement and core performance restoration, after a total of 25,000 cycles. After the third on-wing interval of 5,000 cycles, the engine would be removed due to expiry of the fan and booster LLPs at the 3rd shop visit, having achieved a total of 30,000 cycles. Clearly, premature replacement of the core LLPs at the 1st shop visit (case “B”) represents the application of the workscope optimization criterion for a minimum number of shop visits. The cost of the unused core LLPs lives of 3,000 cycles is balanced with the one less shop visit cost, leading to a reduction in total shop visit costs.

Case “C” is an extreme case of the optimization for minimum number of shop visits. The total number of engine operating cycles considered may be achieved with only one shop visit, after the initial run of 17,000 cycles. During that shop visit, the core and LPT life-limited parts would need replacement, and both core and LPT major modules would require full overhaul workscope applied. Building the engine to a standard of 13,000 cycles at the 1st shop visit may assure reaching the goal of a total 30,000 operating cycles, set as the basis for the comparison of the considered workscope optimization cases. However, the question of whether the engine can achieve the second on-wing interval depends on the ability to produce an engine that meets operator on-wing life expectations at that particular shop visit. Therefore, without a proper assessment of the engine condition at removal, the application of the proposed level of workscope for the analyzed case “C” might not adequately address adverse engine conditions that may exist that could result in a premature engine removal.

The comparison of the cases “A”,”B” and “C”, as well as the resulting total shop visit costs for assuring the engine to achieve 30,000 cycles, are shown in Table 2.

Table 2 Comparison of the workscope optimization criteria

Case	“A”	“B”	“C”
No. of Shop Visits	3	2	1
LLPs Replacement & Module Overhaul	Core@SV_2 & LPT@SV_3	Core@SV_1 & LPT@SV_2	Core&LPT @SV_1
Perf. Restoration	Core @SV_1&SV_3	Core @SV_2	/
Shop Visit Costs	166.6 $/EFC	136.6 $/EFC	106.6 $/EFC

The results indicate that the premature replacement of life-limited parts is justified in terms of achieving lower total shop visit costs per engine flight cycle that are primarily a result of a reduced number of shop visits.

5 CONCLUSION

The performance deterioration of major engine modules and the expiration of life-limited parts are the primary removal causes for engines operating on short-haul operations. The results of this research confirm the possibility of improving the quality of planning engine shop maintenance through reduction of long-term direct maintenance costs. By implementing the appropriate corrections, there is an open possibility to apply the presented workscope optimization approach to other types of turbofan engines.

ACKNOWLEDGMENT

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Contact address:
Branimir Stojiljković
University of Belgrade
Faculty of Transport and Traffic Engineering
11010 Belgrade
Vojvode Stepe 305
E-mail: b.stojiljkovic@sf.bg.ac.rs

UNIVERSITY OF NIS FACULTY OF MECHANICAL ENGINEERING
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TRANSPORT AND LOGISTICS
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HUMAN ENVIRONMENT, ENVIRONMENTAL AWARENESS AND URBAN MOBILITY THROUGH THE LENSES OF PUERTO RICO AND THE BAHAMAS

Magdalena KRSTANOSKI[1]
Ana M. LAZAREVSKA[2]
Daniela MLADENOVSKA[3]

[1)] *Everglades University, Sarasota, FL, U.S.A., Construction Management and Renewable Energy Department*
[2)] *University Ss. Cyril and Methodius Skopje, Macedonia*
[3)] *University Mother Teresa, Skopje, Macedonia*

Abstract

There are significant challenges and risks associated when addressing sustainability efforts, and opportunities in the areas affected after hurricane impact. This study is researching sustainability indicators, environmental aspects for urban inland and waterfront areas, human dimension and urban mobility. Planning assessments in respect to the human dimension, and architecture heritage to understand the present and suggest future strategies, are researched equally emphasizing the needed approach for addressing the uniqueness of the land. Land is influenced by the culture in the area, and resolution of the challenges, is suggested to be built on the principles influenced by the culture and land of application.

Destructive wind forces and excessive rain along the hurricane Maria in Puerto Rico in 2017 and hurricane Dorian in the Bahamas in 2019, left the Caribbean islands with massive destructions, affecting the community, basic services, housing and vegetation. Rebuilding and redeveloping the communities require new approach with sustainable synergetic strategies in mind, addressing the human environment, preserving and restoring the nature (rehabilitation, reclamation and remediation efforts) as well as developing means and methods for future economic growth. As all aspects are equally important, factors related to the cultural specifics, human dimension and architecture, mobility, accessibility, relationship between planning, design and energy, become important indicators for sustainable growth. Remediation is a result of the research and mitigation of the condition that contributed to a deteriorated landscape. One of the aspects for such condition is the contaminated drainage of runoff from a brown field site, that will need remediation, including environmental impact. Reconstruction and rebuilding of communities is not only simple restoration and reproduction of the basic services, but project specific by considering preservation of cultural heritage, historic buildings, landscapes, with implementation of further planning to incorporate energy independence and introduce new management strategies to mitigate all factors into successful opportunity.

For Puerto Rico, two years post hurricane Maria, challenges for implementing sustainable strategies remain. Bahamas are experiencing the aftermath of the hurricane Dorian, which considering the destruction power of both weather events, brings sustainability effort strategies as a common starting point, with further consideration of the cultural uniqueness of the each, to be separately addressed.

Key words: *sustainability indicators, energy, environmental awarness, culture, planning, urban mobility, community impact, design, superfund,*

1 INTRODUCTION

Puerto Rico was affected with two tropical cyclones within short period of time, in September 2017. Hurricane Irma, a Category 5 hurricane and two weeks later Hurricane Maria, a strong Category 4 cyclone, with observed maximum sustained winds of 155 miles per hour, made a direct landfall in Puerto Rico impacting the island of Dominica and Puerto Rico. Both cyclones caused destructive effects on the environment, structures and people. The Hurricane Maria was recorded the first Category 4 cyclone to impact the island of Puerto Rico since 1932. See Fig.1 showing Satellite image Hurricane Maria over Puerto Rico and island of Dominica (Source: U.S. National Oceanic and Atmospheric Administration (NOAA)).

Fig.1 Satellite image of Hurricane Maria as it approaches Puerto Rico

Source: U.S. National Oceanic and Atmospheric Administration (NOAA). NOAA National Environmental Satellite, Data, and Information Service (NESDIS)

Two years later, in September 2019, Hurricane Dorian, Category 5, made a landfall in the Bahamas with 185 miles per hour sustained winds and 25 feet storm surges, causing destruction of Abaco which suffered estimated 85% of the damage and Grand Bahamas 13% of the damage. See Fig.2 showing Satellite image Hurricane Dorian over the Bahamas (Source: U.S. National Oceanic and Atmospheric Administration (NOAA)

Fig.2 Satellite image of Hurricane Dorian as it approaches Bahamas

Source: U.S. National Oceanic and Atmospheric Administration (NOAA). NOAA National Environmental Satellite, Data, and Information Service (NESDIS)

In order to understand the human environment, and urban mobility solutions in the past and in the present, one must understand how nature relates with human proxemics to perceive perception, how the same co-relate with the art and the architecture, and furthermore, recognize how that perception changed over time, along with its awareness for that perception, to be able to predict future action. The so-called laws of perspective, from the point of art - the first expression humans developed before the architecture evolved in various styles over the period of time, are uniquely translated in Puerto Rico from baroque in 1500s, towards Spanish Revival expression, emphasizing social space, stairs concept, natural light and open courtyards. That is a different approach in comparison to the impressionist's use of ambient light, luminosity effects, visual space perspective and light in space, predominantly art expression in the nineteenth and early twentieth century.

Each culture has its own pattern and behavior reflecting in the design and the architecture. As Edward Hall[1] expressed "People carry around with them internalizations of fixed-feature space learned early in life", same applies in the architecture and planning – designing, construction and rebuilding of the cities understanding the needs of the occupants, and planning cities and environment with people and culture in mind. Per Hall, whenever there is cross-cultural borrowing, the borrowed items have to be adopted[1]. In Puerto Rico architecture, this is evident in the *Missionary Society of the Methodist Episcopal Church* in Ponce, built in 1907, designed by the Czech architect Antonin Nechodoma, structure with the design result of a combination between Neo-Gothic, Spanish Revival, Spanish Baroque and Byzantine, as well as on Nechodoma's other design *Georgetti Mansion,* built in 1923, introducing Prairie style, as a result of his practice in Puerto Rico and Dominican Republic (between 1905 – 1928). Further practiced by German architect Henry Klumb, who after his architectural studies in Germany, continued as student and drafter for the famous American architect Frank Lloyd Wright. Frank Lloyd Wright strongly believed in harmony between humanity and nature, cherishing the environment with an open concept. Henry Klumb settled in Puerto Rico and made architectural footprint with the *University of Puerto Rico*, *Museum of Anthropology History & Art*, *Law School Building*, *General Library*, *Caribe Hilton Hotel* in San Juan. And as Le Corbusier, a pioneer of the modern architecture, and one the most influential XX-th century architect, once referred to the relationship between architecture and light as: "Architecture is the learned game correct and magnificent of forms assembled in the light", light and courtyard played and still play an important role in the Caribbean architecture. Even more, Norman Foster's universal message appears to be a mirror image on why specific designs are specific to the each of the Caribbean: "As an architect you design for the present with an awareness of the past for a future which is essentially unknown"[2]

Cities were planned and built based on the history influences, cultural uniqueness, and architects' vision, inspiration, and translation of space, thus urban mobility is very closely related to the historic architecture and design choices. Implementing urban mobility and The Americans with Disabilities Act (ADA) regulations in the Caribbean remains to be a challenge.

Due to the old architecture and styles developed, accessibility and urban mobility were not of a major consideration at the time of the design. The Americans with Disabilities Act although it is enforced in Puerto Rico, as it is in United States, there are areas outside of the major cities that is not applied. This condition surfaced during hurricane Maria and in the aftermath, showing that communities in Puerto Rico did not have emergency plans and procedures to follow to implement for the residents with disabilities. That was specifically affected availability of medical services and social services, that the residents with disabilities depend on for their health and independence. As people for different population perceive and respond to forecast and hurricane differently, in case of Puerto Rico and later Bahamas shows common aspect - that communicating the risk, uncertainty and resolving critical aspects, were not understood, discussed and practiced on the frontend.

On the other hand, Bahamian old architecture resemble British style brought to the country by early British estate owners, with implemented tropical functional and painted light colors that Bahamian builders customized to fit the tropical climate aspect. The characteristics of the structures are functional, with large windows for passive cooling and air circulation purposes and positioned on stilts to prevent flooding, Not significant old architecture present other than 1700s or 1800s and predominantly low rises.

Here we further expand our understanding of the impact of extreme weather and disaster events on the islands, by prior understanding architecture. We focus mostly on the Puerto Rico, noting that recently Bahamas suffered damages of similar nature.This research also contributes to perspective regarding the difficulties of predicting and pattern of reaction as related to the cultural and historical link to the responsiveness in case of weather , Planning and mobility, from the past and how same translates in the design choices, urban mobility and cultural aspects are also explained, and further solutions are suggested. Further we investigate possibilities of how new technology may provide solutions for future growth. The goal of this study is to improve the understanding that concept of planning via increased knowledge about extreme weather and disaster preparedness, response, and recovery from the past occurrences is important.

2 PUBLICATIONS

Kishore, N., at all[3] discussed mortality rates in post hurricane including indirect effects of the aftermaths estimated 4645 versus official count of 64.
Hinojosa, J., at all[4] researched the decade-long housing crises and new residential construction as a result of the cyclon Maria, noting the importance to support involvement of the communities and stakeholders in order to provide solution and propose methods for recovery and rebuild of Puerto Rico.

Keellings, D., et all, 2019[5] discussed climate linked to the hurricane Maria producing maximum rainfall and had the highest total average precipitation of 129 storms that affected Puerto Rico since 1956. They noted the extreme precipitation in recent years in the magnitude of Hurricane Maria has become more evident so as increased sea surface temperatures linked to increased precipitation and such events to be likely increased, as linked to the climate trends.
Talbot, J. et all, 2019[6] are contributing with research on identifying factors and drivers for housing recovery in event when formal response and recovery resources are inaccessible

Kwasinski, A et all, 2019[7], are investigating effects of the Hurricane Maria on the renewable energy, identifying microgrids as a potential technical solution, however the authors are noting complexity of the subject not only from a technical perspective, but also from economic, organizational and management side.
Prime, B., 2011[8] researches how understanding of the historical color influence architectural finishes addressing color schemes and paint patterns across the building typology analyzing buildings as a group versus frequently studied as isolated entities.
This study looks holastically into elements that influence the design and planning and the dependence of the socio-economic factors along with the technical opportunities and identifying possibility to recognize areas that need front end planning and improvements.

3 RESEARCH METHOD AND FACTORS

This research utilizes quantitative data via investigation of factors that are possibly contributing elements for understanding the correlation of the impact of one Hurricane condition outcome and socio economic elements. These are indicators that with careful consideration may assist in front end checklist for prepraredness and also to asist in. redevoping and reconstruction

See Fig.3 with cyclone characteristics and impact force that affected the area

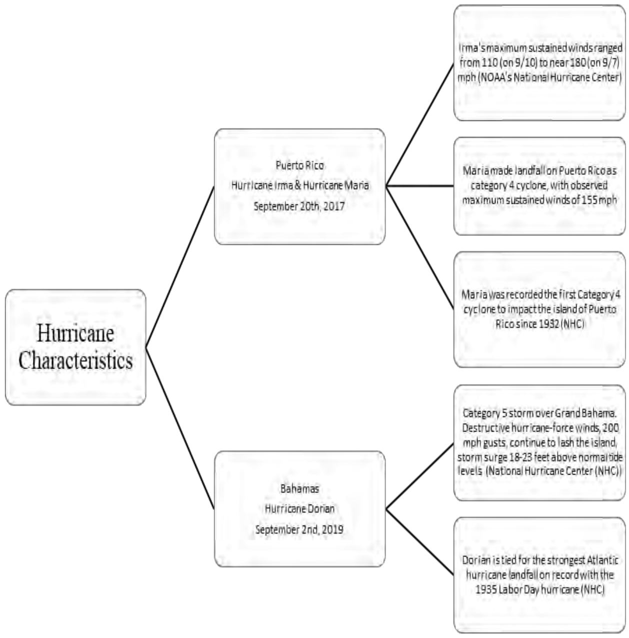

Fig.3 Impact force and area of impact on each cyclone

Effects of Irma not only impacted the land but also the sea, involving large sand displacement and sand distribution along the Florida coastal area and Florida Keys with potential damage of the natural resources, as result of the impact and strenght of the cyclone (NHC)

See Fig. 4 showing crises in the housing market after Maria, which is directly connected with increase of the unemployment and migration. This is reflecting in notable increase of housing vacancy from 2010 from 16.8% to 21.3% in 2017 (US census bureau, 2013-2017). Decrease of housing value over the past decade and specifically after the cyclone's destruction is another contributing factor in slow reconstruction and redevelopment in the post hurricane period. As a result of Maria, Puerto Rico experienced unprecedented level of destruction, excessive flooding that severely affected the existing housing, from not repairable, to roof and foundation damage. Waist deep flooding, mudslides and powerful winds caused not only housing damages but also to concrete foundations of metal utility pools, impacting more than 80% of Puerto Rico power grid and with no potable running water (FEMA)[9].

The above reflected to even bigger housing market crises, uneven housing availability and no demand, and homes left vacant or owed by the bank.

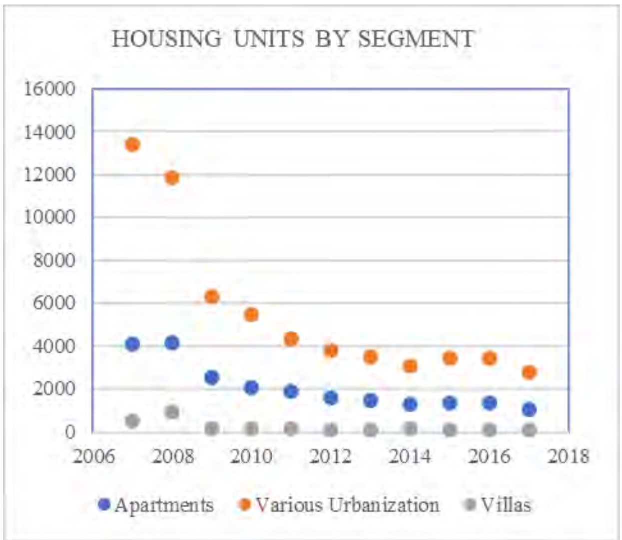

Fig.4 Housing market by segment per year

This developed an opportunity for converting the vacant housing into social purposes by developing a program targeting at the purchase of vacant properties for conversion to social purposes, particulary for homes that were not built up to the code.[10]
In Puerto Rico alone, was estimated $354 million in damage to the housing sector according to the post-disaster assessment, that included replacement costs of destroyed houses and repair (FEMA, Jan. 2018)

As a result of the cyclon, more than 80 percent of the power grid was gone, as well as 21 out of 22 weather stations, cell phone infrastructure and wireless services were affected as well.

The practice of reusing previously developed sites due to the environmental conscientiousness becomes more common. Some of these properties are abandoned sites due to the environmental contamination and are called brownfields. The Comprehensive Environmental Response Compensation and Liability Act (CERCLA) referred as "Superfund" was created in 1980 and made landowners , actual or past liable for contamination found on the property whether the landowner cause of the contamination of not. The idea behind this law was to restore the site to the original state for future development, via process of indentifying, analyzing and cleaning the hazardous substances that may create a risk to human health and environment. In 2002, President Bush signed the Small Business Liability Releif and Brownfield Revitalization Act (SBLR) into law, which changed the old definition of brownfield, addressing liability, funding, support for state programs, municipal waste [11]. Two definitions are applicable to the abandoned site with environmental contamination: brownfield and superfund depending of the level of contamination and groundwater contamination.
In the case or Puerto Rico, superfuns sites are noted on the EPA (Vieques, Dorado, Caguas, Arecibo, Vega Baja, San German, etc)[12] refer to EPA official lits. As cleanin these areas is a complex and timely involved process cyclon activities negatively contribute to the progression process with creating masive flooding, destruction, debree and waste covering the affected areas. With destroyed vegetation and housing, coastal area, with no electricity and access to clean water, and as a result of the power distructive cyclone force, ground contamination remains challenge. More challenging are identifying processes economicly feasible on a long run.
Standard processes involve engineering and technical strategies, such as pasive and active stragies. Methods used from vitrification or stabilization, which increase the impermability of the soil are expensive processes and usually require adding cement or heasting and melting the soil. This way changes the solid media of the soil chemically to reduce transport of contaminats by percolation. The most expensive method is removing material from the site for disposal or treatment [12]. Other processes are: phytormediation via using selected plants to remove of biostabilize contaminats in soil or water, solvent extraction, bioremediation, soil washing, dechlorination, air sparging. Complexity of the process involves design consideration, installation of utilities in the contaminated site, drainage concerns, risk exposure, vegetation on the imacted site, and type of the soil, which is timely evolved process.
Much of the electricity infrastructuire in Puerto Rico was damaged during Irma and maria. Traditionally Puerto Rico's power plants use coal, oil, and natural gas. Most of the power capacity were reported status back operational in April 2018 (leaving residents without power since September 2017) Previous built onshore wind power plants, represented 76 percent of the island's total wind energy, are not operating, same as 32 percent of the island's solar energy sources and 12 percent of battery capacity.[13]
See Figure 5 showing Puerto Rico electric generating capacity (**Source:** U.S. Energy Information Administration, *Preliminary Monthly Electric Generator Inventory*)

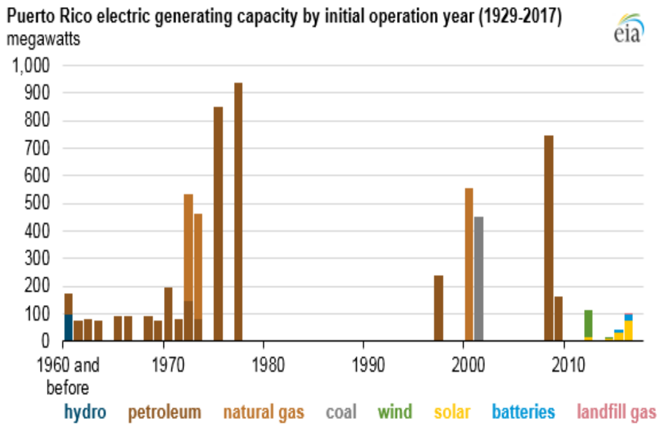

Fig.5 Electric generating capacity by initial operation year (Source: U.S. Energy Information Administration, Preliminary Monthly Electric Generator Inventory)

CONCLUSSION

In the Carribean islands with local tradition aspects to remain close to family and friends and not to relocate, it is of importance to develop community planning processes. As a result of this social cohesion, the residens prefer to remain and rebuild in the areas where they are located. It was noted the budiling codes were not equally implemented on all areas of Puerto Rico, although all regulations applicable to United States are applicable for Puerto Rico as well. With retaining the population with community and poeple in mind, the residents will be encouraged to build more sustainable and resilient structure up to the code versus relocating and moving. Rebuilding will take years. The cyclon destroyed already weak power grid infrastructure. Rebuilding power grid with using renwable resources as an independent source versus tied to the main grid, will bring energy independence, new technology aspect and training opportunity of the local residents in the island, but at the same time is a challenging task, and will require not only social, economical, but also financial and political solutions.

This paper explains that all factors (socio, economic, historical, finiancial, political, ecological, geography of the island) must be considered equailly to propose methods to influence decision makers for sustianable growth.

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Contact address:
Magdalena Krstanoski
Everglades University, Sarasota, FL, U.S.A., Construction Management and Renewable Energy Department
E-mail: mkrstanoski@evergladesuniversity.edu

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RETHINKING URBAN MOBILITY IN DEVELOPING COUNTRIES

***Beti ANGELEVSKA*[1]**
***Vaska ATANASOVA*[2]**

[1)] Department for transport and traffic, Faculty of Technical Sciences, Bitola, R.N. Macedonia
[2)] Department for transport and traffic, Faculty of Technical Sciences, Bitola, R.N. Macedonia

Abstract

Many countries, particularly in the developing world, are experiencing growth, development and urbanization at an unprecedented scale. These changes affect every aspect of their economy, society and environment.
Rises in the demand for the transportation of goods and people will increase the impacts of transport in terms of detrimental effects to people and the environment. Many of these effects like air and noise pollution, congestion and health effects are felt in urban areas in developing and emerging countries in particular. Thus, strategies and new approaches are needed to support sustainability in transport, and for developing countries, would be of much help for achieving the goals of sustainability. Hence, this paper elaborates such an approach in urban mobility: Avoid-Shift-Improve (A-S-I) approach. The concept of A-S-I is a fundamental guiding principle for the development and implementation of strategies and instruments to promote sustainable urban mobility, considering that urban mobility needs to provide mobility opportunities for all.

Key words: *sustainability,transport, A-S-I approach.*

1 INTRODUCTION

Mobility is a key prerequisite for social and economic development. An efficient transport infrastructure is vital for economic production, trade and the movement of goods. Mobility facilitates access to markets, jobs, education and health care. In emerging economies and developing countries, it is crucial for poverty reduction [1].
However, today's culture of mobility – particularly the Western model to which many developing countries aspire – is unsustainable [1]. It is based on the notion that building more transport infrastructure – and creating more traffic – is the way to promote prosperity and development.
Unsustainable transport causes severe problems including pollution, energy consumption, accidents, rises inequity, declines quality of life and causes other threats associated with climate change. All these negative side effects harm people and the environment. It is expected that both the overall emissions and the demand for energy in transport will continue to rise in the next decades unless appropriate policy measures are introduced [2].
In order to achieve an equitable and sustainable model of mobility for the future, a step forward in transport policy is essential. Thus, urban mobility issues are of foremost importance to support the mobility requirements and require new approaches. The aim is to enhance the capacity of local decision makers and urban/transportation planners to formulate and implement appropriate policies that contribute to sustainability in urban transport in developing countries.
Strategies to make transport more sustainable should be designed to achieve a wide set of objectives using comprehensive combinations of available policy instruments. Any concept attempting to make mobility more sustainable works differently in developed and developing countries and even within these country-groups [2].
The concept of Avoid-Shift-Improve (A-S-I) is widely accepted as a guideline for policies to promote sustainable mobility [2]. This means that transport policy should (in this order) attempt to reduce the need to travel and shorten trip lengths, promote a shift to sustainable modes and to improve the sustainability of all modes.

The Avoid-Shift-Improve (A-S-I) approach allows an analysis of the important issues of sustainable transport including transport demand management, improved public and non-motorized transport, environmental protection, road safety, and gender in transport. In order to achieve sustainability, it also provides some means such as economic and financial instruments, institutional improvements, capacity building, regulation of markets and environmental standards.
The A-S-I approach will promote sustainable urban mobility, implemented as a policy intervention or as a long-term strategy in order to minimize negative effects caused by transport suggesting and recommending appropriate measures for developing countries.

2 EMERGING AND DEVELOPING COUNTRIES: THE CONTEXT OF URBAN MOBILITY

In the space of just a few decades, urban areas across the world, in both developed and developing countries have become increasingly automobile-dominated and less sustainable. In developing countries in particular, cities have experienced a rapid growth in transport-related challenges, including pollution, congestion, accidents, public transport decline, environmental degradation, climate change, energy depletion, visual intrusion, and lack of accessibility for the urban poor [3]. In more developed countries, particularly in Northern Europe, some cities have witnessed a trend of reclaiming urban space from the automobile and prohibiting cars from major parts of downtown areas and/or confining them in other ways [3].

In the coming decades, it is expected that approximately 90% of the planet's population growth will occur in the cities of developing countries [4]. These cities are struggling to meet the increasing demand for mobility and investment in transport.

Emerging economies and developing countries face a multitude of mobility challenges. In urban areas with a high population density and businesses concentrated in a relatively confined space, traffic congestion is generally the main problem. Combined with inefficient infrastructure, this causes time and productivity losses and is already having a severely detrimental effect on economic development [1].

Besides the lack of integrated strategies and solutions, there is generally also a shortage of reliable data and survey techniques as a basis for solving problems [1]. Planners also lack the evaluation skills needed to assess whether measures adopted have been successful and learn lessons, theoretical and practical, from mistakes and failures. As a consequence, many cities are trapped in a vicious circle. They steadily expand their infrastructure, sacrificing more and more valuable urban space and producing even higher levels of congestion, noise and emissions, which they then try to combat using the same methods as before [1].

The subject of sustainability in transport offers a wide array of pressing questions. Hence, there is a pressing need to improve the sustainability of transport in order to reduce all its impact on environment and economic growth. Also, it should be considered that emerging approaches are those that should be first choice during the planning of urban mobility (table 1).

Table 1 The changing landscape of urban mobility

Conventional approaches	Emerging approaches
Supply and capacity	Demand management and resilience
Focus on mobility	Accessibility
Street as road for vehicles	Shared between all modes
Physical dimensions	Social dimensions
Vehicle-oriented	People-oriented and customer-focused
Motorised transport	Hierarchy of modes
Travel as a derived demand	Travel also a valued activity
Minimisation of travel times	Reliability of travel times
Petrol taxes/vehicle registration fees	User-pay models
Private car ownership	Car-sharing and ride-sharing

Source: [5]

In short [6]:

- Politicians, government institutions and planning processes need to emphasize accessibility over mobility.
- Cities need to be more compact, encourage mixed land use, and prioritize sustainable modes of mobility such as non-motorized transport, in order to develop sustainable mobility systems.
- Improved urban planning will be critical in designing and retrofitting cities to better accommodate sustainable modes.
- Policies to encourage sustainable urban mobility must take into account social, environmental, economic and institutional dimensions of sustainability. This calls for more inclusive framework for the planning, design and provision of urban mobility systems and services.

Today, the development of sustainable transport, including the delivery of accessible, cost effective and sustainable mobility, represents a major challenge for many countries [4]. This involves the requirements for safe, inclusive, resilient and sustainable transport, all of which go hand-in-hand with more stringent requirements in terms of safety and security, reducing the impact on the environment and climate change, and improving energy efficiency.

3 SUSTAINABLE TRANSPORT: SIGNIFICANCE AND BENEFITS

Sustainable transport is linked to many other sectors, complicating the analysis and resulting policies. Sustainable mobility in general takes account of economic, social and environmental aspects.
Figure 1 illustrates the challenges of making mobility sustainable. Transport has a number of direct benefits and plays a crucial role in the economic development of societies, thus enabling economic growth. However, this has repercussions, most notably on settlement structures and negative externalities in terms of CO_2 and air pollutant emissions, congestion and health impacts (caused by accidents or air and noise pollution) [2].

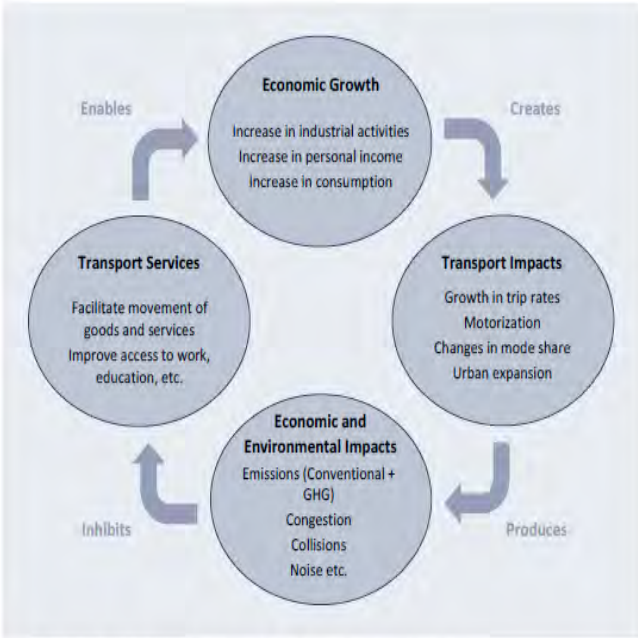

***Fig. 1** The challenges of making mobility sustainable*
Source: [2]

A sustainable transport system provides goods and services to all inhabitants of an area, is affordable, safe and efficient and protects the environment and its services [2]. The benefits of sustainable mobility are given at next figure.

The challenge to make transport sustainable stems from the observation that transport services enable economic growth, creating transport impacts, which in turn produce economic and environmental impacts, which thereby might inhibit transport services and quality of life [2].

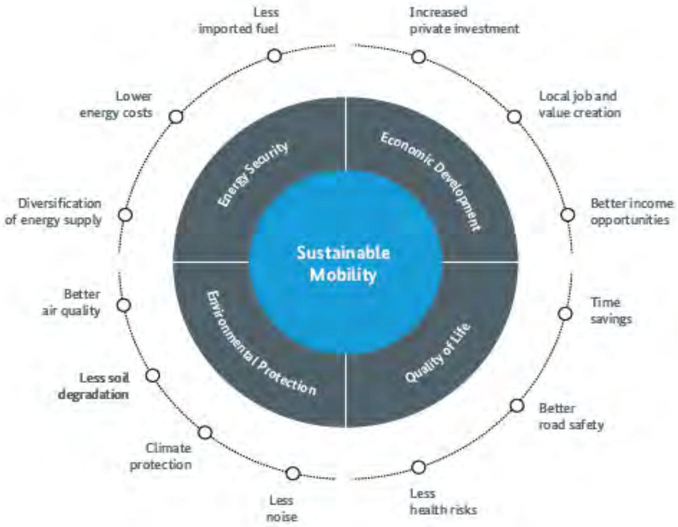

***Fig. 2** Benefits of sustainable mobility*
Source: [7]

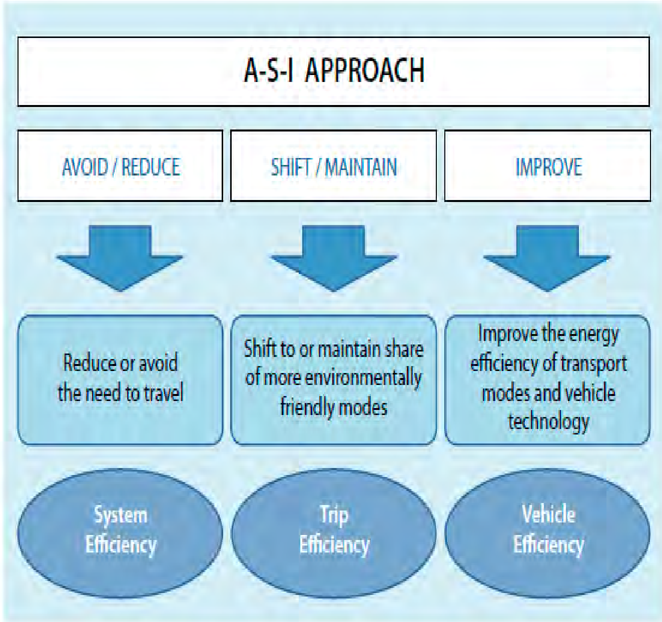

***Fig. 3** The concept of A-S-I approach*
Source: [8]

4 NEW APPROACH TO SUSTAINABLE MOBILITY: THE AVOID – SHIFT – IMPROVE (A-S-I) APPROACH

How can we avoid unnecessary traffic and shorten journeys? How can we ensure that bus and rail travel and cycling become competitive alternatives to the private car? And how can we reduce the overall volume of traffic, both passenger and freight? The answer is to create multi-functional compact cities with short distances, integrated transport systems in urban areas and optimized policies. This type of strategy will safeguard the supply of goods, facilitate equitable access to markets, jobs and cultural amenities, and boost political participation [1].
This should be combined with a visionary approach to urban design which puts people first and helps to reestablish urban spaces as meeting points for recreation, social interaction and exchange. This radical new approach not only involves the transport sector: it must encompass the related areas of urban and spatial planning, architecture, and economic policy.
The transport sector must support this transformation with appropriate policy strategies. A significant role, in this context, is played by the Avoid-Shift-Improve (A-S-I) approach [1].
The A-S-I approach entails three main pillars [8]:

1. Avoid/reduce
2. Shift/maintain
3. Improve.

Firstly, "avoid" refers to the need to improve efficiency of the transport system. Through integrated land use planning and transport demand management the need for travel and the trip length may be reduced.

Secondly, the "shift" instruments seek to improve trip efficiency. A modal shift from the most energy consuming urban transport mode (i.e. cars) towards more environmentally friendly modes is highly desirable. In particular, the shift towards the following alternative modes [8]:

- non-motorized transport (walking and cycling): they represent the most environmentally friendly options
- public transport (bus, rail, etc.); although public transport also generated emissions, lower specific energy consumption per km and higher occupancy levels imply that the associated CO_2 emissions per passenger km are lower compared to cars.

In many developing and emerging countries active and public transport are the main modes of transportation. Governments should seek to maintain and further improve this situation [7].

***Fig. 4** The A-S-I approach through pictures*
Source: [7]

Thirdly, the "improve" component focuses on vehicle and fuel efficiency as well as on the optimization of transport infrastructure. It pursues to improve the energy efficiency of transport modes and related vehicle technology [8]. Furthermore, the potential of alternative energy use is acknowledged.
The A-S-I approach follows a hierarchy: "avoid" measures should be implemented first, secondly "shift" and finally the "improve" measures.
Concepts that aim to make mobility more sustainable work differently in developed and developing countries (table 2).

Table 2 Avoid, shift and improve and the state of economic development

Principle	Developed countries	Developing Countries
Avoid	Reduction of vehicle kilometres travelled	Avoid generation of vehicle kilometres travelled
Shift	Shift from private vehicles to public transit and non-motorized transport	Prevent shift from public transit and non-motorized transport to private vehicles
Improve	Amend and downsize existing vehicles	Make future vehicles as clean as possible and discourage the up-sizing of vehicles

Source: [2]

The decisive distinction is that individual transport has to be reduced in developed countries whereas its growth has to be curbed in developing countries [2]. In both cases technological developments play a supporting role.

5 BENEFITS OF THE A-S-I APPROACH

The benefits of improving the three aforementioned dimensions – transport demand, mode choice and technology – can be substantial. The A-S-I approach has the potential to contribute to emissions reduction beyond current expectations [8]. Vitalization of public spaces, better urban air quality and many other important co-benefits can be expected from the application of the A-S-I approach.

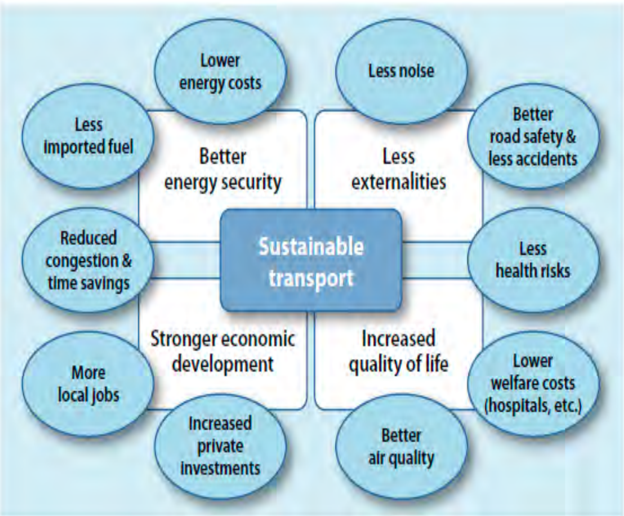

***Fig. 5** Benefits of the A-S-I approach*
Source: [8]

The policy instruments in the Avoid-Shift-Improve (A-S-I) approach can be categorized into planning, regulation, technological measures, economic incentives and information (figure 6) and they differ in their ability to reduce the need to travel, induce modal shift or improve transport efficiency [2].

The Avoid–Shift–Improve approach helps attract diverse stakeholders and build support for political and institutional reforms [4].

Strategies to <u>Avoid</u> unnecessary travel and reduce trip distances [4]:

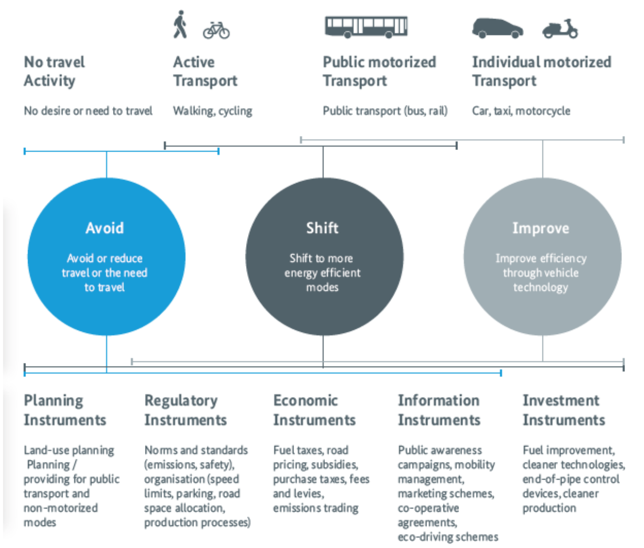

***Fig. 6** Instruments in the A-S-I approach*
Source: [7]

- formally integrate land-use and transport planning
- achieve mixed-use development and medium-to-high densities along key corridors
- institute policies, programs and projects as a means to reduce unneeded travel.

Strategies to <u>Shift</u> towards more sustainable mobility solutions [4]:

- improve public transport services
- require non-motorized transport components in transport plans
- reduce the urban transport mode-share of private motorized vehicles
- achieve significant shifts to a more sustainable supply of mobility services.

Strategies to <u>Improve</u> transport practices and technologies [4]:

- diversify towards more sustainable transport fuels and technologies
- set progressive, appropriate and affordable standards for fuel quality, efficiency and emissions
- establish effective vehicle testing and compliance regimes
- adopt intelligent transport systems
- achieve improved freight transport efficiency.

The Avoid–Shift–Improve approach provides a framework for prioritizing solutions to maximize benefits of sustainable transport [4].

6 NEXT STEPS

Recommendations for sustainable mobility are given in three categories, for implementation by national and local governments and all related public and private stakeholders. By implementing these recommendations, international organizations, businesses and civil society organizations will also have a role to play. The recommendations relate to [4]:

a) *Policy planning*: creating supportive institutional, legal and regulatory frameworks; making transport policy and investment decisions based on social, environmental and economic dimensions; developing sustainable transport systems and the technical capacity of transport planners and implementers, especially in developing countries; improving road safety through legislation and public policy; engaging people as partners for advancing sustainable transport solutions.

b) *Financing*: promoting the diversified funding sources and the coherent, constructive funding, charging and fiscal frameworks that sustainable transport systems and projects need; participation of private capital; increasing international development funding, including climate funding by international organizations and multilateral development banks.

c) *Technology*: promoting sustainable transport and energy innovation and technologies while staying as neutral as possible; this should include direct government investment and policies that enable and encourage private sector investments through various incentives and incentive-supporting structures.

7 CONCLUSION

The rapid and often unplanned and uncoordinated growth of urban areas has seriously compromised existing transportation systems and significantly increased the challenge of creating new transportation systems, especially in developing countries. The environmental and social impacts are significant and directly related to quality of life and urban productivity in these countries.

Relying solely on technical innovations, alternative fuels or specific modes of transport will not solve the problems described [1]. The only solution which offers a genuine prospect of success is an integrated package of measures aimed at avoiding unnecessary travel, reducing distances, providing the most sustainable forms of passenger and goods transport, and maximizing the efficiency of transport systems with technological innovations and alternative technologies [1]. Strategies to change public attitudes and encourage acceptance of sustainable forms of mobility have a key role to play.

There is no single dominant instrument nor is there a single solution for all national and regional contexts [2]. The complexity of urban transport policies calls for integrated and comprehensive programs that take regional and even city-specific circumstances into account.

Inspired by the principles of sustainability, one alternative approach focuses on the mobility needs of people instead of car infrastructure. The approach, known as A-S-I (from Avoid/ Reduce, Shift/Maintain, Improve), seeks to achieve significant greenhouse emission reductions, reduced energy consumption, less congestion, with the final objective to create more livable cities [7].

This means that transport policy should (in this order) aim to reduce the need for transport and shorten trip distances, promote a shift to more sustainable modes and improve vehicle and system-level efficiency through technological innovation and alternative fuels [2].

The Avoid–Shift–Improve approach provides a framework for prioritizing solutions to maximize the benefits of sustainable transport. The A–S–I approach is increasingly accepted as a useful framework within which to take action in support of sustainable transport [4].

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Contact address:
Beti Angelevska
Department for transport and traffic, Faculty of Technical Sciences,
Bitola, R.N. Macedonia

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ASSISTIVE TECHNOLOGIES AND URBAN MOBILITY PROBLEMS OF DISABLED PEOPLE IN NIS

Đorđe MILANOVIĆ [1]
Saša MILANOVIĆ [1]
Vladislav BLAGOJEVIĆ [1]
Danijel MARKOVIĆ [1]

[1] *Faculty of Mechanical Engineering, University of Niš*

Abstract

This paper presents assistive technologies which are used as auxiliary devices with an aim of facilitating everyday lives of the disabled people. Their definition and division are given. Afterwards, the problems these persons are facing in Nis are analyzed. The problems are related to the use of the public transport and, in order to be clearly understood, they are divided into: 1. line recognition, 2. access to the vehicle, 3. positioning in the vehicle, 4. ticket buying. Beside the use of the public transport, problems associated with moving through the city are also analyzed. Parallel to those problems, some solutions as good practice examples developed by chosen European cities are shown, which have been successfully functioning for many years and being of service to millions of people every day.

***Key words**: disability, assistive technologies, accessibility, urban mobility*

1 INTRODUCTION

Assistive technologies encompass everything that can in any way improve and facilitate everyday activities of the disabled people. These technologies can be defined in different ways, but the most comprehensive definition was proposed by **Assistive Technology Industry Association – ATIA** [1]: *Any item, piece of equipment, software program, or product system that is used to increase, maintain, or improve the functional capabilities of persons with disabilities*. Such defined assistive technologies provide flexibility and offer a wide range of possibilities when deciding about the choice of a particular technology.

Assistive technologies were mentioned for the first time in the ***Individuals with Disabilities Education Act –*** **IDEA**, which was published in 1990. Putting into effect the *Individuals with Disabilities Education Improvement Act* in 2004, with the aim of better understanding, assistive technologies were classified into [2]:

- devices – means which help the disabled people in different ways;
- services – activities and actions which directly help the disabled people in choosing, supplying and using the devices.

In addition, there are other classifications which take into consideration different aspects of the disability. One of the criteria could be the type of the disability and, in accordance with that, categories can be distinguished, e.g. assistive technologies for helping people with difficulties in moving, assistive technologies for helping blind and visually impaired persons, assistive technologies for helping the hearing impaired people, etc. [3]. On the other hand, observed from the aspect of the activity which they are supposed to facilitate, regardless of the form and type of the disability, assistive technologies could be divided into those for movement, reading, writing, computer use, etc. [5]. Generally speaking, a wide range of different assistive technologies is available (*Fig. 1*). One group is made up of quite simple supporting devices easily obtained, which are not expensive and do not need any additional training. Beside this group, there are complex devices which are more expensive, with additional features to adequately meet customer requirements, and their use depends on the customer ability and adaptation to the environment in which they live.

Fig. 1 *The classification of assistive technologies*

2 URBAN MOBILITY OF THE DISABLED PEOPLE – PROBLEMS AND SOLUTIONS

2.1 Public trasportation use

Generally speaking, the use of public transport could be observed through the following phases, which are performed routinely, with paying no or little attention, but which could present significant impediments for the disabled people [4, 5]: 1. planning the journey; 2. finding the right stop or station; 3. finding the entrance to the station; 4. navigation inside the stations; 5. finding the rights stop; 6. knowing where the vehicle exactly stops; 7. finding the door of the vehicle and finding one's way into it; 8. paying for services; 9. finding a seat; 10. recognizing the right stop for exit; 11. navigation inside the station; 12. finding the exit; 13. finding the destination. Because of that, disabled people are not often able to use the public transport independently, and concrete problems these people are facing when using it could be further divided into [5]: line recognition; access to the vehicle; positioning in the vehicle; ticket buying.

2.1.1 Line recognition

Nis (Serbia) – Bus line names in the city of Nis are of a visual type. They are labeled on the busses and at the bus stops there are signs like the traffic ones with numbers and names of bus lines that pass and stop at a particular stop. But these signs are often scribbled and covered with advertising and other messages, making them difficult to understand. The installation of the information panel in the city centre, on King Milan square presents a good example. Namely, all the public transport vehicles have real-time monitoring via GPS signal, and based on that, the LCD screen shows information about the time when the next bus is arriving. Besides the precise time of the bus arrival, some service information is also shown on the monitor (e.g. the latest news, the current temperature, the time, the bus-ticket price etc). However, this screen does not emit audio messages, and because of that blind and visually impaired persons are not able to use public transport independently.

Sofia (Bulgaria) – At the city centre, there are several bus-stops equipped with information panel which supplies customers with real-time information about the movement of public transport vehicles, i.e. buses. In order to make public transport accessible to blind and visually impaired people, those panels have been adapted and upgraded with special audio devices [6]. This project was initiated by the Sofia Urban Mobility Centre, with the cooperation of the Sofia Regional Department of the Union of Blind People in Bulgaria. Firstly, future customers were interviewed in order to make a list of the most frequent bus stops. Funds for the realization of the project were provided by the city of Sofia.

Madrid (Spain) – All the bus stops and buses in the city of Madrid are equipped with devices emitting audio and visual information about the distance of the bus, line number, direction, etc. [7]. Audio messages at the bus stops are activated by pressing the button on the information panel. These messages can also be activated by a smart-phone, using the mobile application which provides all the necessary information about the functioning of the public transport.

2.1.2 Accessing the vehicle

Nis (Serbia) – The necessary adaptations for enabling the disabled people on bus stops in Nis have not been performed in order for them to independently access the vehicles. Due to high curbs on bus stops, adequate positioning of buses is not possible. The positioning is additionally made more difficult by cars which are often parked in areas provided for busses to stop. On the other hand, although there is a sufficient number of low-floor buses equipped with ramps for easier entrance and exit of wheelchairs and other mobility aids, as well as of mothers with strollers, it happens that they are not always in order.

Krakow (Poland) – Bus stops of public city transport in Krakow are adapted in two ways. One solution is by curbs being raised to the level of the vehicle floor, and in that case the ramps are not necessary. Rather, the vehicles can be entered directly from the bus stops [8]. The other possibility is to remove the curb from the bus stop, which would enable a more adequate positioning of the bus and facilitated installation of the ramp [9].

2.1.3 Positioning in the vehicle

Nis (Serbia) – Positioning in the vehicle is related to the existence of a designated space provided for wheelchair users. This space should be equipped with safety belts for securing the wheelchair during the ride, as well as special buttons for warning and stopping the vehicle. Such space exists in buses of the public city transport in Nis. However, it is not sufficiently used and the equipment in not always in order.

Berlin (Germany) – Transport of passengers in Berlin is carried out by the subway, trams and buses. Bus transport is performed with around 1,300 buses on 350 lines [10]. All buses are adapted to wheelchair users and they are equipped with ramps for facilitated entrance and exit of these persons. These are usually mechanic ramps which are manually installed by the driver, and they are located on central or rear doors of the bus. Similarly, there is a designated area in all buses for these users which is equipped with safety equipment and a button which can be used to inform the driver if someone wants to leave the vehicle.

2.1.4 Purchasing tickets

Nis (Serbia) – The ticket system in Nis is unique for all transporters. Individual tickets are bought in the vehicle from the conductors or drivers and they are printed on the spot, while prepaid monthly or half-monthly tickets can be bought on several locations in the city. What still presents a great problem are numerous misuses and attempts of not paying the ticket for a ride, which can be the result of insufficiently developed consciousness of citizens and, at the same time, an inadequate penalty policy.

Barcelona (Spain) – Tickets for public city transport in Barcelona are bought at a ticket vending machine and they are valid for all types of city transport [11]. The ticket vending machines are adapted for the blind and the visually impaired persons and their independent movement and use of public city transport is enabled. Namely, the ticket vending machines are activated through remote control and they emit sound signals to make it easier to find them. In addition, the ticket vending machines have buttons with Braille characters, and they offer the possibility of voice commands. In order to facilitate the cancellation of tickets, they have a special tactile notch on the left side for those purposes.

2.2 Other problems of urban mobility

Disabled people come across numerous other obstacles in moving through the city. Because of high curbs, it is significantly difficult for wheelchair users to cross the streets and to reach the sidewalks (*Fig. 2*). In order for the blind and visually impaired persons to be able to move independently, various systems and devices are needed to give them guidance for movement by emitting sound or vibrating signals. At the same time, devices are needed which emit audio messages at crossroads during the green light at the traffic light, in order to facilitate the road crossing for these persons. However, although there are endeavors to improve the safety and in that way greater independence of the disabled people, companions still may be needed to be with them the whole time and to give them the necessary help. For instance, in some cities (Rotterdam, Paris and others) there are volunteers who are appropriately trained to help the disabled people [12, 13].

Fig. 2 *High curbs in Nis as obstacles for the movement of wheelchair users*

2.2.1 Inaccessible sidewalks

Nis (Serbia) – Independent movement of persons who use wheelchairs in Nis is made more difficult by inaccessible sidewalks, that is, high curbs. In other words, the number of ramps which should enable safe stepping on the sidewalks or walking paths is insufficient. In those places where they exist, such ramps are often inadequate, at a great angle (steep) and they are not in compliance with the standards proscribed by the Rulebook on technical standards for accessibility („Official Gazette of the Republic of Serbia“ no. 46/2013).

Helsinki (Finland) – Within the project „Helsinki for everyone“, the aim of which was to improve urban mobility and accessibility, adaptation of the public city transport, streets and sidewalks was performed. Besides other things, a new type of curbs with lowered edges was set, of different colors from the rest of the sidewalks, with the aim of facilitating movement for wheelchair users, and persons with impaired vision [6].

Rotterdam (Holland) – In order for the disabled persons to be enabled to move independently through the city, specific guidelines were established and certain modifications performed with the aim of adapting the city environment. Among other things, the guidelines prescribe that the elevation differences along footpaths must not be larger than 2 cm, bumps of the paths must be smaller than 3 cm, while the width of the path must be at least 180 cm [13].

2.2.2 Guidance systems

Nis (Serbia) – Tactile paths are used as systems for guiding blind persons in Nis. The city has recognized their importance for independent movement of these persons, so they were set at places which have most frequency. However, there are certain problems related to their safe use. Namely, the city has not been covered sufficiently by tactile paths yet, and the paths themselves are often non-functional and inadequate. This implies not only abrupt interruptions of paths, but also numerous obstacles which can be found along the paths, such as garbage cans, manhole covers, parked cars, and even café tables and chairs (*Fig. 3*).

Fig. 3 *Tactile paths for the movement of the blind and visually impaired persons in Nis*

Birmingham (Great Britain) – Beside the tactile paths and traditional white walking sticks, there are other, significantly more advanced and sophisticated systems for guidance. Such is the case of the concept of “smart” walking sticks, developed by a group of students from the University in Birmingham [14]. The essence of this idea is that the walking sticks have an installed camera and a special memory space for the storage of photographs of familiar persons. The camera records the faces of people on short distances (up to 10m) and after that comparisons are performed with the earlier recorded photographs. If there is a match, the user is notified through a vibration that a familiar person is in his or her proximity and he or she is guided towards the direction of that person through audio guidance.

2.2.3 Sound signalization on crossroads

Nis (Serbia) – Traffic lights which emit sound signals, besides the visual ones, are necessary in order for blind persons to be enabled to move independently and to cross the road safely. In Nis, there are several such traffic lights which emit short sound signals during green light. More advanced audio devices which emit a voice message about the name of the street during the green light and a special sound signal when the traffic light shows a red light exist on two locations in the city, but only one is currently in order.

Barcelona (Spain) – Traffic lights in Barcelona are equipped with audio devices which emit messages when the green light is on and they are activated through special remote controls which blind persons carry with themselves. The traffic light system and the regulation of traffic is further developed and integrated in such a way that the firefighters and other services for providing help can change the lights on the traffic lights in order to reach the destination as quickly as possible [15].

2.2.4 Street lights

Nis (Serbia) – Inadequate street lights can negatively affect the safety of the disabled persons, especially in the evening. A large part of Nis is illuminated by a low-temperature incandescent lighting. LED lighting which is significantly more efficient according to many parameters has been installed only on a few locations in the city. The problem which occurs frequently is the unadjustment of the layout and height of trees and the street lighting poles. In other words, lighting is often “hidden” in treetops, which reduces the amount of light on the streets. Because of this, some parts of the city remain almost completely unlighted.

Birmingham (Great Britain) – The whole of street lighting in Birmingham was replaced and a total of 90,000 new LED lights were installed. The light can be adjusted in all lights, depending on the daily light. On the other hand, the system is monitored in real time for the purposes of collecting data about the effects, in order to perform the optimization of lighting. All this finally allows the realization of savings in expenditures [16].

Eindhoven (Holland) – In Eindhoven, movement sensors are placed on the street lights poles, and the optimization of lighting is carried out in such a way so that the quantity of light is reduced if there are no pedestrians. By using lighting of various colors, the safety of pedestrians is improved and, on the other hand, a positive effect on the living environment is realized. Such lighting also has the function of emphasizing the pedestrian and bicycle crossings on streets [16].

CONCLUSION

Although assistive technologies present a relatively new area of human work, some of them are significantly sophisticated and they improve the everyday life of the disabled people very much. Since a great number of these technologies exists, it is difficult to include them all and group them. Some of these technologies can be used in public city transport (vehicles and infrastructure) and its adaptation in order to make it accessible to a large number of people. Their use is significant also in enabling independent movement of the disabled people in urban environments. Solutions applied in the chosen cities of the European Union have been developed with cooperation of local bodies of the government, organizations and associations of the disabled people, but also all other interested parties. In Nis, and generally speaking in Serbia, initiatives for such projects are missing, and therefore the motivation for their implementation.

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Contact address:
Saša Milanović
Mašinski fakultet u Nišu
18000 NIŠ
A. Medvedeva 14
E-mail: msasa@masfak.ni.ac.rs

4. CONSTRUCTIONS AND DESIGN ENGINEERING

UNIVERSITY OF NIS FACULTY OF MECHANICAL ENGINEERING

THE SEVENTH INTERNATIONAL CONFERENCE
TRANSPORT AND LOGISTICS

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INFLUENCE OF CAR DOOR CAVITY DESIGN ON INGRESS/EGRESS ERGONOMICS

***Elena ANGELESKA*[1]**
***Antonio CVETKOVSKI*[1]**
***Mila DIMCHOVA*[1]**
***Nenad SIMONOVSKI*[1]**
***Darko TREZIOVSKI*[1]**
***Sofija SIDORENKO*[1]**

[1)] Faculty of Mechanical Engineering, "Ss Cyril and Methodius" University in Skopje
Karpoš II bb, P.O. box 464, 1001 Skopje, Republic of Macedonia

Abstract

The most important customers"demands in the phase of car selection are accessibility and seat comfort. From that point of view, the main goal is to obtain maximum comfort for all of the passengers. Many of the motions during the exploitation of the vehicle, especially the ingress/egress movement, are very complex and depend on the users" anthropometry, age, physical condition and health. Our research includes assessment of both (head-first and hip-first) strategies of ingress movement, as well as egress movement. The study includes a focus group of 13 volunteers of both gender, different age and stature, and 9 popular city cars. Several qualitative and quantitative research methods are applied (‚fly on the wall"method and questionnaires) and conclusions include suggestions for designing car door cavities for improved ergonomics.

***Key words**: Anthropometry, Ingress/Egress, Vehicle Ergonomics, Vehicle Design*

1 INTRODUCTION

One of the most important criteria for drivers, as well as the vehicle manufacturing companies, is to ensure a pleasant sensation while accessing the car, which means feeling comfortable and safe. The first contact the driver has with the vehicle happens while opening the car door and entering inside. Therefore, every person, regardless of gender, age, and body type, needs to feel pleasantly while doing that in order for the design to be a success. The issue of comfort during ingress/egress attracts the attention as an activity that has an important role in providing that pleasant feeling in the first contact with the vehicle [1]. This activity is strongly influenced by a combination of design and anthropometric factors that have an approximately equal significance.

However, the presence of people is a significant limiting factor due to the large number of morphological differences among them and can sometimes cause a design solution which is not accepted by everyone. Therefore, special attention needs to be paid to the ergonomic features. P. Vink, E. A. P. Koningsveld and J. F. Molenbroek, in their research concerning the positive outcomes of participatory ergonomics in terms of higher comfort and productivity [2], pinpoint the fact that even though sometimes ‚ergonomics is coupled to illness, complaints or guidelines, which could have a negative connotation", it is in fact the most positive approach to design. Broadening the ergonomic knowledge helps improve the end-users experience.

Thinking about satisfying the needs of specific target users, many theoretical and experimental researches are conducted. For example, a research which aims to improve the usability of vehicles by elderly and pathological populations, uses a mixed group of test subjects to record kinematic and dynamic data of ingress/egress [3] that can help develop strategies for simplifying the activity for them. Another similar simulation is done in a research with the crews driving ground vehicles in order to improve their over-all performance [4]. But what happens when the design needs to meet the comfort requirements of a broader and not as specific target group?

Making the effort to attract more buyers, car manufacturers have developed multiple choices of shapes, sizes and ways of opening for car doors (Table 1). All these variations have their own pros and cons considering ergonomic features.

Table 1 List of non-standard car door designs

Type of opening	Example	Image
Butterfly	Porsche 911 GT1	
Canopy	Saab Aero-X	
Gull-wing	Tesla Model X	

Scissor	Lamborghini Aventador	
Sliding	Peugeot 1007	
Suicide	Opel Meriva	
Swan	Renault Kwid concept	

In this research, in order to gain better insight about the way different car door openings define different ingress/egress comfort levels, an ergonomic research consisting of 5 stages was done. The usual approach in ergonomic researches regarding automobile features is doing them virtually, by the use of software and virtual mannequins of extreme anthropometric sizes [5]. In order to attain originality, this research is conducted with real subjects – human participants. This method enabled an insight into the individuality of the participants, and a view of the unconscious ways of entering and exiting the vehicles that might not be considered in virtual analysis.

2 RESEARCH METHOD

The research process itself was consisted of 5 phases: preparation; observation and recording the ingress/egress od the participants; conducting a survey; analysis of the data; and drawing conclusions.

- Preparation
- Vehicle selection – selecting several commercial vehicles adequate for analysis.
- Participant selection – selecting a focus group consisted of candidates with drastically different body measurements, gender and age.
- Survey preparation – creating a simple scale for grading the perceived ingress/egress comfort.
- Observation
- Observation of the ingress/egress process of each participant with every vehicle and taking notes.
- Recording the process.
- Conducting a survey.
- Analysis of the data
- Reviewing the recordings and gathering the notes of all the observers in a spreadsheet.
- Reviewing the answered surveys and creating a chart presentation.
- Comparing the results.
- Drawing conclusions – based the gathered qualitative and quantitative data.

2.1 Vehicle selection

The testing was conducted using 9 city vehicles that are commonly driven, but differ from each other by size and design (Table 2). The door shapes of the vehicles were outlined and compared (Fig.1,2) in order to pinpoint the difference that makes one shape more ergonomic than another later on, when the results of the research are analysed.

Table 2 List and description of the selected vehicles

	Vehicle	Properties
1	Volkswagen Golf IV Year: 1999	Doors: 3 Origin: Germany Class: Compact
2	Chevrolet Cruze Hatchback Year: 2009	Doors: 3 Origin: South Korea Class: Compact
3	Hyundai Getz Year: 2006	Doors: 5 Origin: South Korea Class: Supermini
4	Suzuki Splash Year: 2011	Doors: 5 Origin: Japan Class: City Car
5	Opel Corsa B Year: 1998	Doors: 3 Origin: Germany Class: Supermini
6	Mazda 6 Year: 2011	Doors: 4 Origin: Japan Class: Mid-size
7	Peugeot 107 Year: 2005	Doors: 5 Origin: France Class: City Car
8	Mercedes Benz GLK 220 Year: 2008	Doors: 5 Origin: Germany Class: Luxury Crossover
9	Ford Fusion Year: 2005	Doors: 5 Origin: Germany Class: Mini MPV

***Fig. 1** Door outlines of the selected vehicles*

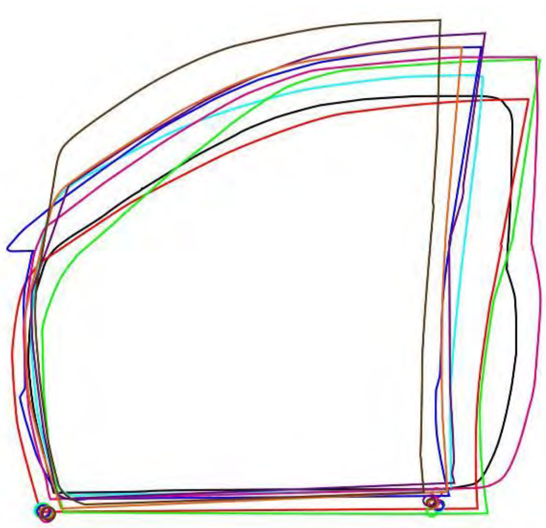

***Fig. 2** Comparison of the door outlines*

***Fig. 3** Participant silhouettes and percentiles*

2.2 Participant selection

The selection of participants was made based on previous analysis of anthropometric measurements [6]. The aim was to make a selection of male and female personas belonging to different body size percentiles (low and high percentiles). The body size measurements taken into consideration as a selection criteria were – height and weight – since they are most closely linked to the perceived comfort while entering or exiting a car. The final chosen participants for the focus group were 13 licenced adult drivers, out of which 10 were male and 3 were female, aged from 20 to 56 (Table 3). Their percentiles for height and body mass varied from 30% to 90% which means that nearly all potential types of users were considered (Fig.3).

Table 3 Description of the participants

	Sex	Age	Height (cm)	Height PCTL	Weight (kg)	Weight PCTL
1	m	24	186	91	85	84
2	f	55	169	81	66	70
3	m	20	177	52	65	32
4	m	21	177	52	70	52
5	f	20	167	72	48	8
6	f	31	172	91	54	31
7	m	24	173	31	89	89
8	m	27	173	31	97	96
9	m	56	180	68	80	75
10	m	20	190	97	80	75
11	m	53	174	36	80	75
12	m	24	186	91	80	75
13	m	29	183	82	90	90

2.3 Survey creation

As an addition to the observation method used as a qualitative technique in the research process, a quantitative approach was used as well. This was done by composing a survey for the participants where they were asked to give a comfort rating for each one of the nine automobiles respectively. The grading scale was a Likert scale consisted of 5 points, with number 5 meaning 'very comfortable' and number 1 meaning 'very uncomfortable'. This tool is common for assessing comfort-discomfort and it has been proven to be successful for investigating qualitative variables [7]. In this research, it was chosen and used in an effort to present the ergonomic features of the cars as an objective reality that can be measured [8] and make sure the results from the observation method, regarding the behaviours in the chosen setting, matched the perceptions and reactions of the individuals themselves.

2.4 Method

The research process began by placing all 9 cars in a neutral environment, gathering the participants and asking them, one by one, to conduct the activity of entering and exiting each car (Fig.4).

***Fig. 4** Several photographed enter/exit movements of different personas of the focus group in/out the 9 different cars*

The participants were advised to use their own most natural way of ingress/egress. The process included assessment of both (head-first and hip-first) strategies of ingress movement, as well as egress movement. The whole activity, for each subject-vehicle, was observed, but also filmed, in order to present the results in a more detailed and precise manner. After finalizing the activity, the participants answered the survey questions

3 RESULTS

3.1.Analysis and results from the observation method

The analysis of the gathered notes from the observation process resulted with short conclusions for the ergonomic features of each car.

Volkswagen Golf IV

Entering and exiting this car seemed uncomfortable for nearly all the participants of the focus group. A slight discomfort was noticed with the participants belonging to a height percentile >80 who curved their necks more during the process.
Also, the participants belonging to a higher weight percentile >80 looked crammed inside the car while trying to enter and adjust their seating position. Even though the car door cavity is wider since this is a 3-door model, the main comfort issue seemed to be in the lower height of the roof and slight curvature of the cavity in the top front (Fig.5).

Fig. 5 *Door cavity outline of Volkswagen Golf IV*

Chevrolet Cruze Hatchback

There was visible neck and spine curving with almost all participants, therefore the ingress/egress did not appear very ergonomic.
However, the body adjustment in the first moments inside the car seemed easier in comparison with the Volkswagen Golf. Here, the cavity has a smaller width, however the movements were slightly more comfortable in comparison to the first model due to the over-all bigger volume of the vehicle and the higher roof. The discomfort was a result of an even larger slope in the top front of the cavity (Fig.6).

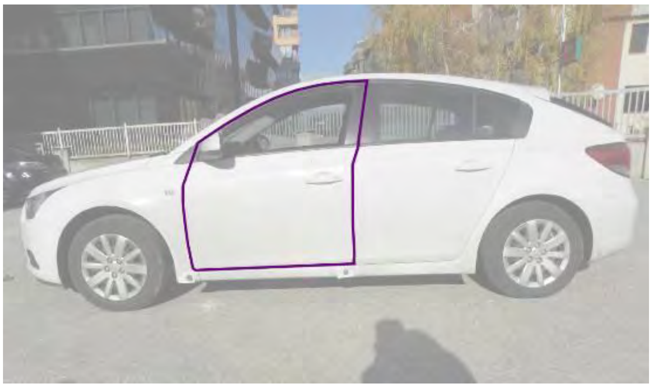

Fig. 6 *Door cavity outline of Chevrolet Cruze Hatchback*

Hyundai Getz

The ingress/egress process was similar with the one concerning the Volkswagen Golf IV. The neck and spine curving were apparent, especially with participants with a height percentile >80. The body adjustment looked slightly uncomfortable inside the tighter volume of the Hyundai. The car door cavity has a similar shape to the one of the Chevrolet Cruze with slightly smaller dimension.
The roof height is somewhere in between the first and second model, thus the ergonomic features seemed to be "more or less" the same (Fig.7).

Fig. 7 *Door cavity outline of Hyundai Getz*

Suzuki Splash

The entering and exiting process in this car seemed very easy for all participants. The neck curving and bending was minor, even for those belonging to a higher height percentile.
Therefore, this car appeared to have good ingress/egress ergonomics, the participants did not linger while stepping in, seating and stepping out, they looked comfortable and pleased.

This model has a smaller width of the door opening, however the height of the roof and the shape of the cavity are significantly different. The shape is very rectangular, the lines are straight, the roof height is biger and the gradient of the roof line has a smaller absolute value, meaning is not as steep (Fig.8) – the result of these features is better ingress/egress ergonomics.

Fig. 8 *Door cavity outline of Suzuki Splash*

Opel Corsa B

This car was troublesome for the participants, their annoyance and discomfort were apparent during entering and exiting. The bending, and spine curving was big because of the tight entrance space and small volume of the car. They also all looked uncomfortable when seated inside the car, being very close to the steering wheel.

This 3-door car has a smaller cavity width in comparison with the other 3-door model – the Volkswagen Golf IV and the roof is drastically lower than the roof of the other so far examined models (Fig.9). This seemed to be the greatest issue resulting with comfort issues.

Fig. 9 *Door cavity outline of Opel Corsa B*

Mazda 6

The perception concerning this vehicle was that, generally, the body curving and neck and spine bending while entering and exiting it was minor, especially with the female participants.
The ergonomic features seemed decent, the ingress/egress was fast and looked comfortable even for personas with higher weight and height percentiles.

This vehicle has the steepest roof sloping, and lowest roof and floor height (Fig.10). The ingress/egress comfort noted during the observation process is likely due to the larger over-all volume of the vehicle and widest car door opening in comparison to the other 4 and 5-door cars.

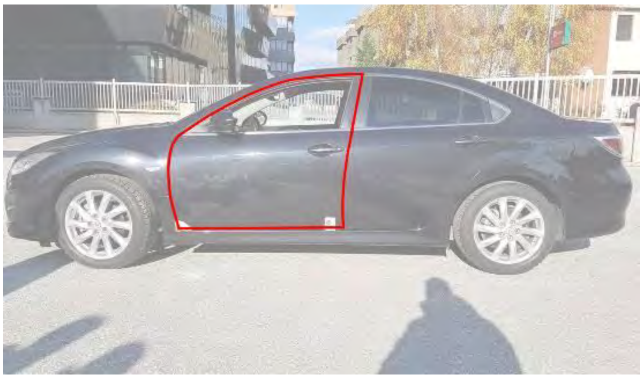

Fig. 10 *Door cavity outline of Mazda 6*

Peugeot 107

Even though this car is smaller, the ingress/egress was not a significant problem for the participants. The bending and neck/spine curving were definitely present, but not drastic, they were just more emphasized for participants with a height percentile >90. While analysing the data from the observation and looking at the car door opening outline in greater detail, it was concluded that the straighter lines of the outline, decent roof height and an outline shape closer to a rectangle add up to create satisfying ergonomic features for a smaller city vehicle (Fig.11).

Fig. 11 *Door cavity outline of Peugeot 107*

Mercedez Benz GLK 220

The entering and exiting ergonomic features for this car were also decent, the participants did not appear troubled during the process. The higher floor of the car in comparison with the other cars was not a problem, on the contrary it seemed like it improved the comfort. However, in this case, a slightly wider door would be a better ergonomic solution for more comfortable entering. The Mercedes Benz has a door opening outline which looks like a trapezoid in the front zone (where the windscreen and roof connect), rather than the standard continuous curved line of the other vehicles (Fig.12).
This is important because it makes the entering area of the cavity closer to a standard door and thus being comfortable during ingress/egress. The outline in the part separating the front and back door is slightly angled toward the front.

Perhaps if the back line was straighter it would open up the cavity width a bit more and the ergonomic features would be improved.

Fig. 12 *Door cavity outline of Mercedes Benz GLK 220*

Ford Fusion

There was apparent neck curving and bending with all participants while stepping inside this car because of the roof inclination. The stepping out looked more comfortable. Over all, the ingress/egress process was not difficult for the participants, especially for the females. Looking at this outline, there are some similarities with the one of the Mercedes Benz. If the roof line here was not as inclined – if instead it was trapezoid-looking and the roof was a bit higher, the outlines of these last studied cars would be more alike, and the ingress/egress ergonomic features of the Ford Fusion would be improved (Fig.13).

Fig. 13 *Door cavity outline of Ford Fusion*

3.2. Results from the questionnaire

The survey results were summed up and are shown on the graph below (Fig. 14).

According to the respondents, the most ergonomic car for entering is the Suzuki Splash which received an average grade for „entering comfort" of 4.7, followed by the Mazda 6 and Ford Fusion, both with average grades of 4.5.

Regarding exiting, the first place for most comfortable is shared by the Suzuki Splash and Mazda 6, both receiving an average grade for „exiting comfort" of 4.6, and the second place is shared by the Mercedes Benz and Ford Fusion with average grades of 4.5.

From the results, it is apparent that the Suzuki Splash and Mazda 6 were perceived as most comfortable during ingress/egress. The car voted for least comfortable was the Opel Corsa B.

Fig. 14 *Average comfort assessment*

4 CONCLUSIONS AND DISCUSSION

What can be concluded from this case study is that the ergonomic features of the car door openings are closely linked to the geometric aspect of the shape of the door opening itself. The more geometric the shape of the door, the more comfortable it is to get inside the car and exit it. This means, that shapes closer to a simple rectangle are more likely to be ergonomic than the curved car door shapes. This makes sense, since straighter forms do not block the body and require less spine and neck curving and bending while stepping in or out of a car. In addition, the higher the car roof is, and the higher the floor, the easier the ingress/egress.

However, cars with higher roofs and floors and geometric shapes are not as aerodynamic as cars with lower height and organic forms. Therefore, if the goal is to create a sports car that is intended to achieve higher speeds, it is expected that the ingress/egress will not be very ergonomic. But, if a smaller, city car is being designed, a car that needs to meet the needs of a wider demographic, the safest approach would be to use a geometric shape for the opening and be mindful of the car roof height.

If we take a moment to look at the outlines again and compare the car door opening of the city car with most comfortable ingress/egress and least comfortable ingress/egress, the drawn conclusion will be confirmed and even more obvious (Fig.15). The Suzuki Splash is characterized by a nearly rectangular outline, high roof, straight lines. In contrast, the Opel Corsa B has a lower roof, organic lines and steeper roof inclination.

Most comfortable ingress/egress | Least comfortable ingress/egress

Fig. 15 *Comparison of the car door opening outlines of the cars with most and least comfortable ingress/egress*

An interesting finding is that the Mazda 6, graded one of the most comfortable vehicles in this case study, has a lower roof height and a curvy design of the door opening. This seems to contradict the previous conclusions. But, if we look and compare all door opening outlines (Fig.1, 2), we can clearly see that this model has a wider opening in comparison with most of the other car models. This means that with mid-size, family cars that need to have a longer length, and decent aerodynamic features, a lower roof won"t compromise the ingress/egress ergonomics if the opening is wide enough.

One more point that needs to be emphasized is that besides the shape of the door opening, the ingress/egress ergonomics are also influenced by other factors related with the interior design – volume, seat position, seat height, distance to steering wheel and cockpit etc. For example, the Opel Corsa B, which has the nearly the same roof height as the Mazda 6, was perceived as the least comfortable of all vehicles. The reason for this is most likely to be the tighter interior of the smaller vehicle.

Therefore, it can be concluded that vehicle ergonomics is a complex subject that combines many factors and requires thorough researches. The ingress/egress comfort of the driver is influenced by the:

- Shape of the door opening
- Door opening width
- Height of the car roof
- Height of the car floor
- Degree of opening of the car door
- Car seat placement
- Car seat height
- Distance to steering wheel and cockpit
- Interior volume of the car

The findings from this case study can serve as guidelines in other ergonomic researches in the process of designing vehicles. The applied research methods can be used in the same sequence and manner in order to examine what the best solutions for shapes of car door openings would be. Despite the advancement of technology and software, sometimes is better to consider conducting tests with real-life, human participants, despite the additional time and costs required. With software tests some of the human reactions can be omitted and the human perceptions and emotions are not taken into consideration fully. Investing in more research while the design process is at an early stage means less mistakes and a higher likelihood for a successful design.

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Contact address:
Elena Angeleska
Faculty of Mechanical Engineering, “Ss Cyril and Methodius” University in Skopje
Skopje
E-mail: elena_biljanoska@hotmail.com

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ANALYSIS OF LOADING TOOTH MANIPULATOR FOR BREAKING OF CRAWLER TRACTOR

Vesna ***JOVANOVIĆ***[1]
Dragoslav ***JANOŠEVIĆ***[1]
Predrag ***MILIĆ***[1]
Jovan ***PAVLOVIĆ***[1]

[1)] *Faculty of Mechanical Engineering, University of Niš*

Abstract

The first part of the paper presents a general mathematical model of a crawler tractor with a tooth manipulator for breaking - a ripper. The second part of the paper presents the results of the analysis of the Brana komerc - Kruševac ripper. The analysis covers the kinematic and dynamic parameters of the ripper, as well as the assessment of the possibility of installing the Branka komerc - Kruševac ripper on a Liebherr PR 716 XL caterpillar tractor weighing 14600 kg.

Key words: crawler tractor, tooth manipulator for breaking

1 INTRODUCTION

The paper contains a part of the research results related to the reliability analysis of the installation of the breaking tooth manipulator - ripper of the Brana komerc - Kruševac crawler tractor on the PR 716 XL crawler tractor (Fig.1a) by Liebherr. The Brana komerc ripper is a variant of the GM TG-110 crawler tractor produced by IMK 14. October Kruševac to which an attachment plate was added. The plate is designed to bind to the ripper on one side and to the other on a Liebherr PR 716 XL tractor [1].
The analysis includes kinematic and dynamic parameters of the ripper, as well as an assessment of the possibility of installing the ripper Brana komerc - Kruševac on a Liebherr PR 716 XL crawler tractor weighing *14600 kg*.

2 PHYSICAL MODELS

The kinematic chain of the Brana komerc ripper consists of four basic members: the connecting plate L_2 (Fig. 1b), the lower lever L_3, two of the same upper lever L_4 and the bracket with three teeth for breaking L_5.The connecting plate L_2 is an adaptation plate, of welded construction, which has four identical eyelet lugs on the one side of the Liebherr PR716XL crawler tractor and on the other side the lugs that attach the lower and upper levers and the ripper cylinder. The members of the kinematic chain of ripper are welded structures, except the upper levers which are formed by cutting from steel plates. The teeth of the ripper are tied to the bracket by a vertical joint that allows the teeth to rotate freely depending on the lateral breaking resistance. The members of the kinematic chain are connected by rotating joints to sliding steel bushes, forming a mechanism for the shape of a parallelogram.
The drive member of the ripper mechanism is a two-way hydraulic cylinder L_c connected, with spherical joints, one end for the eyelets on the connecting plate and the other end for the bolt that connects the upper lever and the tooth carrier.
The required parameters of the members of the kinematic chain of the ripper are determined according to the construction documentation of the ripper from Brana komerc and the technical characteristics of the hydraulic cylinder are given in Table T1.
Liebherr tractor PR716XL has caterpillar mouvement mechanism with hydrostatic motion transmission and front manipulator with a flat board tool, *3145 mm* wide and *1100 mm*

Table 1 Characteristics of the hydraulic cylinder [1]

Hydraulic cylinder piston diameter	*160 mm*
Hydraulic cylinder piston rod diameter	*70 mm*
Initial length of the hydraulic cylinder	*700 mm*
Ended length of the hydraulic cylinder	*995(1045) mm*
Maximum hydraulic cylinder pressure	*14,0 MPa*
Power flow hydraulic cylinder	*73 l/min*

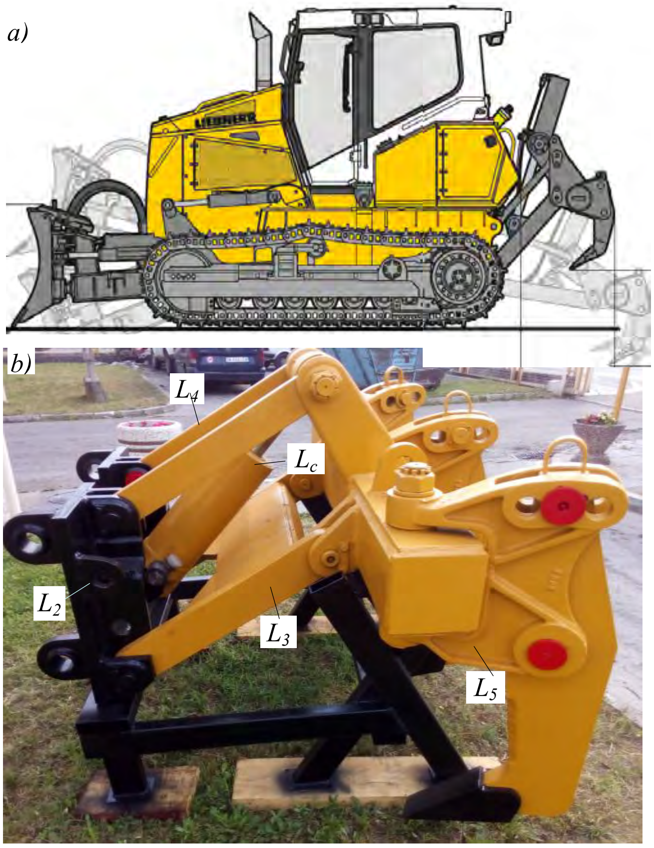


Fig. 1 *Physical models: a) Liebherr PR 716 XL crawler tractor, b) Brana komerc ripper*

high with drive mechanisms that allow changing the angle of the board, in both directions, in the horizontal and vertical planes.
The required tractor characteristics (Table T2) were determined on the basis of the available documentation and analysis and review of the physical model of the PR716XL tractor while operating on Zeljin Mountain [3].

Table 2 Characteristics of the tractor *Liebherr PR716XL*

Total mass of tractor without ripper	*14600 kg*
Diesel engine power	*93 kW*
Caterpillar length	*2600 mm*
Track width of caterpillar	*560 mm*
Movement speed *[km/h]*	Pulling force *[kN]*
1,5	*190*
3	*96*
6	*49*
9	*32*

3 MATHEMATICAL MODEL

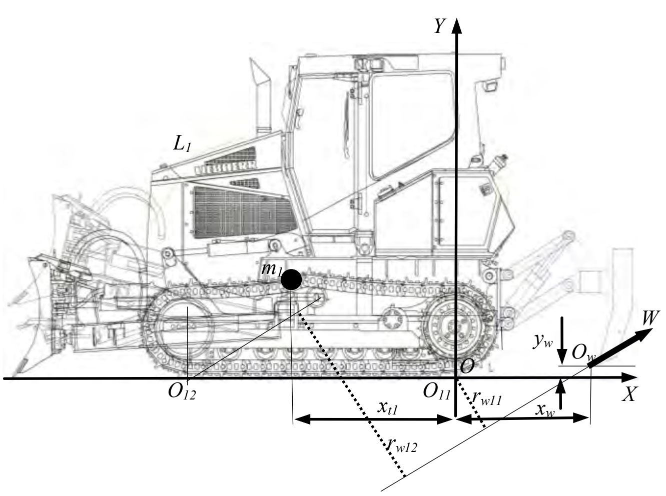
Based on the physical models of tractors and rippers, a mathematical model was developed to analyze the kinematics and loads of the ripper. Tractor L_1 with mathematical model (Fig. 2) in conjunction with the kinematic chain of the ripper from Brana komerc observes in the absolute coordinate system *OXY*, with the axis *OX* lying in the horizontal plane of the machine's support, and the vertical axis *OY* passing through the axis of the caterpillar drive sprocket. Connecting plate L_2 is on the side, with bolts O_{21} and O_{22}, attached to tractor L_1, and on the other side, the lower L_3 and the upper lever L_4 of the ripper at their ends are connected to the plate by rotating joints O_3 and O_4, O_5 and O_7, binds the tooth carrier L_5.
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 and parameters that determine the positions of the center of mass m_i and the center of the joints to which the member binds to its adjacent members. When analyzing the ripper load, the operating conditions of the ripper determined by the coefficient of adhesion of the tracks were simulated. When analyzing ripper load the operating conditions of the ripper are simulated determined by the coefficient of adhesion of the tracks on the basis of the movement of the tractor $\mu_p=1$ and the coefficient of impact load of the ripper $k_u=1,2$.
For simulated operating conditions, the analysis determined the forces in the ripper joints at the action of the possible tensile force of the ripper on the tip of the ripper tooth and the gravitational forces of the members of the kinematic chain of the ripper.
The possible breaking force W is determined by the minimum value: the breaking forces W_s of the breaking resistance determined from the conditions of stable operation of the tractor (non-lifting and non-sliping) and the boundary forces W_c of the breaking resistance that can be overcome by the maximum force Fc of the ripper cylinder:

$$W=min\ \{W_s, W_c\} \tag{1}$$

The boundary force Ws of the breaking resistance is determined from the conditions of stable operation of the tractor (non-lifting and non-sliping) (Fig. 2)[4-5]:

$$W_s = \begin{cases} \dfrac{g\sum_{i=1}^{6} m_i\left(l + x_{ti}\right)}{r_{w21}} & \forall \alpha_w \geq 0^o \\ \mu_p g \sum_{i=1}^{6} m_i & \forall \alpha_w = 0^o \\ \dfrac{-g\sum_{i=1}^{6} m_i x_{ti}}{r_{w11}} & \forall \alpha_w \leq 0^o \end{cases} \tag{2}$$

where: l - caterpillar length, r_{w11}, r_{w12}- the action of the digging resistance force for the traction line O_{11} or O_{12} depending on the angle α_w of action of the digging force, x_{ti} – the coordinate position of the center of mass of the members of the kinematic tractor chain with the ripper.



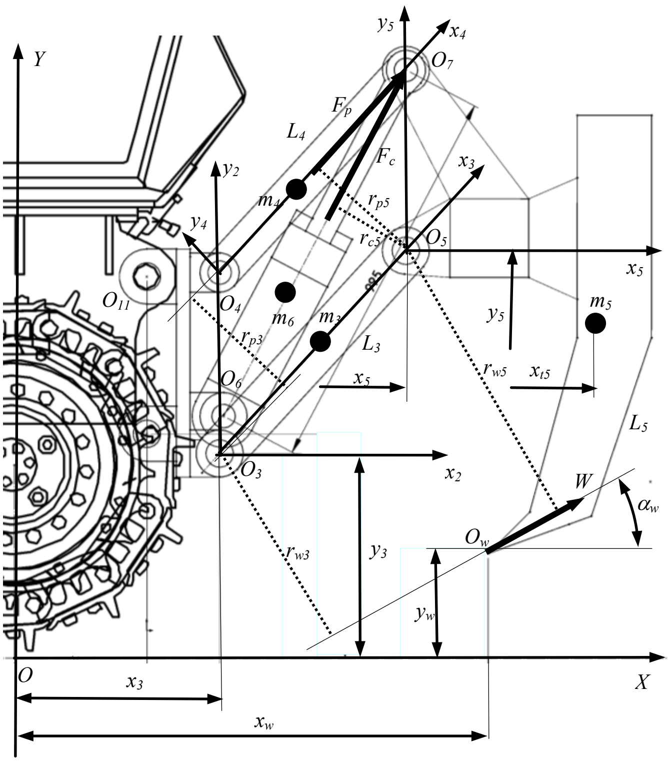


Fig. 2 *Mathematical Model of a Liebherr PR716XL Crawler Tractor and a Ripper Brana komerc*

The boundary force Wc of the breaking resistance that can be overcome by the maximum force F_c of the ripper hydraulic cylinder from equilibrium conditions ΣMO3 = 0 for the O_3 ripper joint expressed by the equation:

$$W_c \cdot r_{w3} - F_c \cdot r_{c3} - F_p \cdot r_{p3} - M_{g3} = 0 \qquad (3)$$

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

$$W_c \cdot r_{w5} - F_c \cdot r_{c5} - F_p \cdot r_{p5} - M_{g5} = 0 \qquad (4)$$

where: r_{w3}, r_{w5} - the action arm of the digging resistance force for the axes of the joints O_3 and O_5 of the, r_{c3}, r_{c5} - the action arm of the maximum force of the ripper hydraulic cylinder for the joints O_3 and O_5, F_p - the force in the levers L_4, r_{p3},r_{p5} - the force action arm in the levers for the joints O_3 and O_5, M_{g3}, M_{g5} - the moments of gravitational force of the individual members of the ripper for the joints O_3 и O_5.
By changing the force F_p in the levers expressed in equation (3):

$$F_p = \frac{W_c \cdot r_{w5} - F_c \cdot r_{c5} - M_{g5}}{r_{p5}} \qquad (5)$$

in equation (4), the breaking force is finally obtained:

$$W_c = \frac{M_{g3} - M_{g5}\dfrac{r_{p3}}{r_{p5}} - F_c\left(r_{c5} - \dfrac{r_{p3}}{r_{p5}}r_{c5}\right)}{r_{w3} - \dfrac{r_{p3}}{r_{p5}}r_{w5}} \qquad (6)$$

where is: $r_{w3}=(x_w-x_3)\cos\alpha_w+(y_3-y_w)\sin\alpha_w$, $r_{w5}=(x_w-x_5)\cos\alpha_w+(y_5-y_5)\sin\alpha_w$

4 RESULTS ANALYSIS

Based on the defined mathematical model, software was developed by which certain possible ripping resistance forces of the ripper depending on the angle of action of the breaking resistance ($\alpha_w=0^o$, 35^o, -45^o) and the breaking depth y_w and the force in the ripper joints.

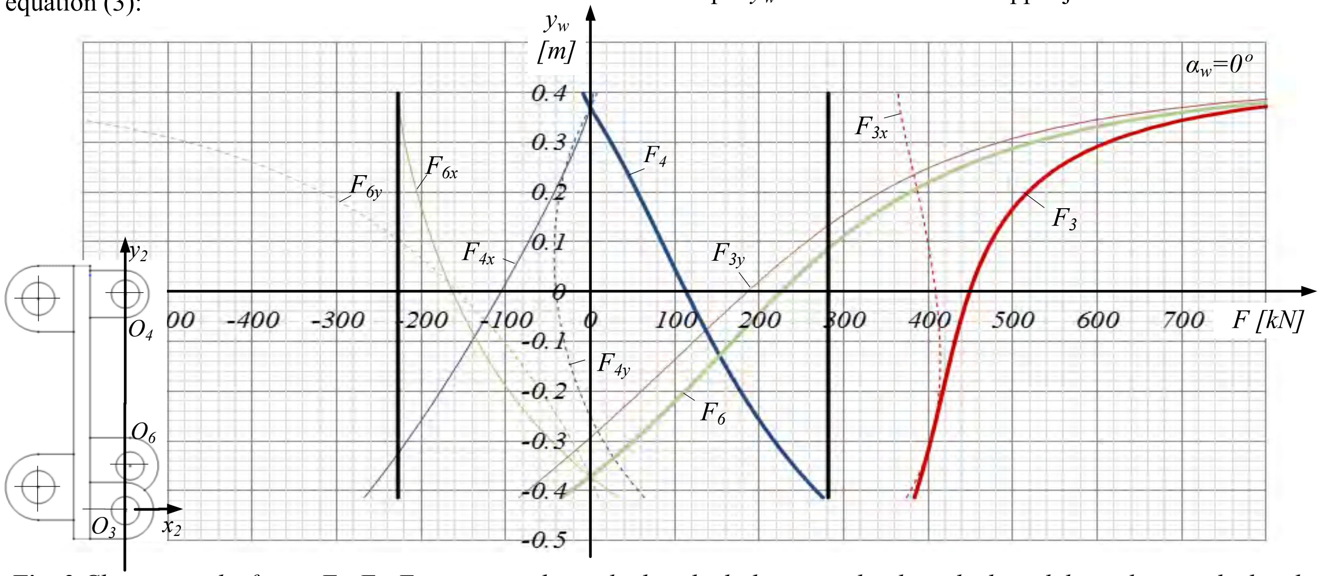


***Fig. 3** Changes in the forces F_3, F_4, F_6 acting on the eyelet by which the ripper binds to the board depending on the height of the yw at the angle of action of the resistance $\alpha_w=0^o$*

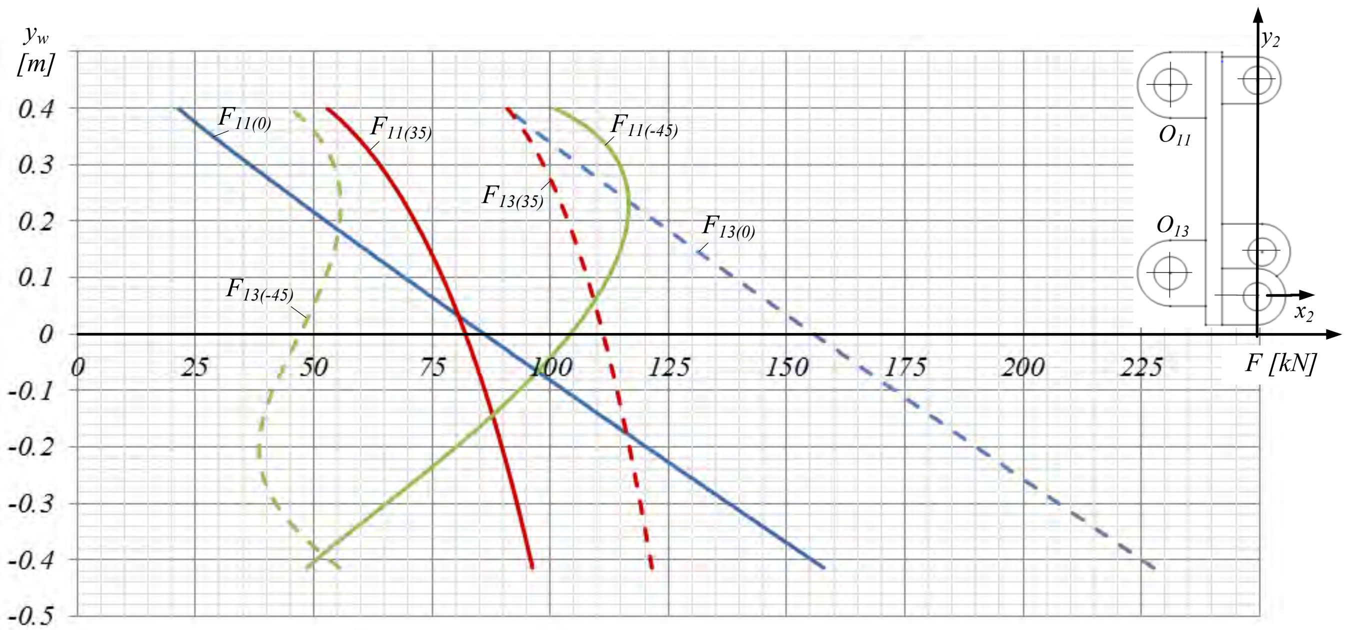


***Fig. 4** Changing forces F_{11}, F_{13} acting in upper O_{11} and lower O_{13} joints to attach tractor tractor plate, depending on the angles (0^o, 35^o, -45^o) of the action of the breaking resistance and the breaking height y_w*

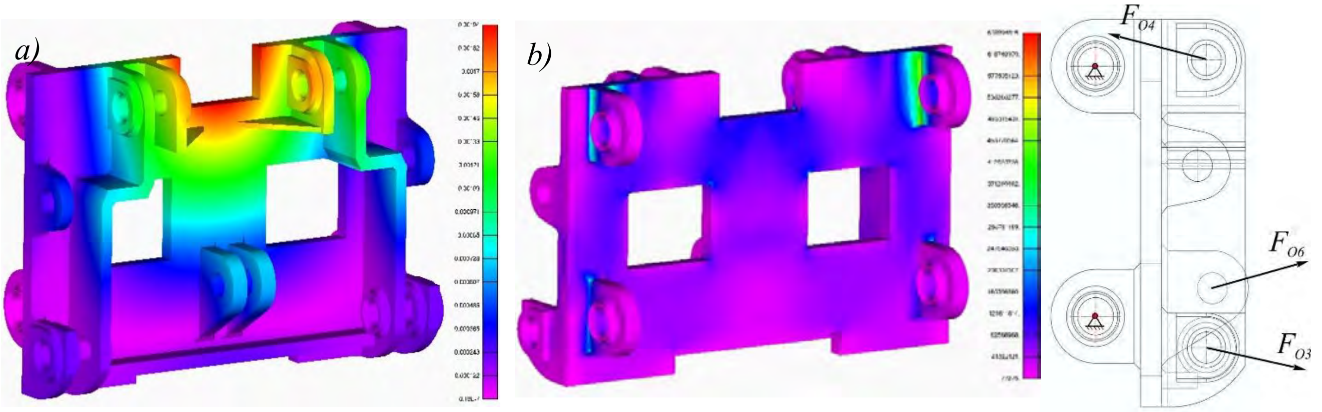


Table 3 Force in board joints at resistance force $W= 188\ kN$ and angle $\alpha_w=0^o$

F_{O3} [kN]			F_{O4} [kN]			F_{O6} [kN]		
F_{O3X}	F_{O3Y}	F_{O3}	F_{O4X}	F_{O4Y}	F_{O4}	F_{O6X}	F_{O6Y}	F_{O6}
501.2	-113,5	513,8	-365,6	87,8	376,0	50,4	14,5	52,6

Fig.5 *Structural analysis of the ripper board: a) model deformation [m], b) solid Von Misess stress [N / m²]*

Resultants F_3, F_4, F_6 and the components $F_{3x,y}$, $F_{4x,y}$, $F_{6x,y}$ of forces acting in the joints O_3,O_4 and O_6 that the ripper binds to the board for the angles of action of the tensile force $\alpha_w=0^o$ are given in figure 3. The results of the F_{11}, F_{13} forces acting in the upper O_{11} and lower O_{13} joints to attach the adapter plate to the Liebherr PR 716 XL crawler tractor depending on the angles α_w (0^o, 35^o, -45^o) of the breaking resistance and the breaking height yw are shown at figure 4.

Structural analysis of the adapter plate was performed for four different cases of ripper loading at different depths and heights, with different angles of action of the forces and different intensities of the possible force of breaking resistance. The work defines (fig. 5) the deflections and voltage states of the connecting board at a resistance force $W= 188\ kN$ and an angle $\alpha_w=0^o$.

CONCLUSION

Conducted ripper testing the companies Brana komerc d.o.o show that the kinematics of the ripper mechanism have approximate values of the maximum depth of tear and slightly less maximum height of the tip of the tooth than the ripper that Liebherr incorporates on his model tractor PR 716 XL.

Structural analysis covers only the adaptation (connecting) plate, the upper lever of the Brana komerc ripper and the bolts that attach the adaptation plate to the ears of the Liebherr PR 716 XL tractor. Since the TG-110 crawler tractor manufactured by IMK 14. October Krusevac, which incorporates a ripper similar to the Brana komerc ripper, has a mass slightly smaller than the weight of a Liebherr PR 716 XL tractor, slightly larger ripper loads are possible on a Liebherr tractor that does not would endanger the teeth, tooth brackets and lower lever of the Brana komerc ripper.

The results of the analysis show that the shear stresses and surface pressures for the bolts of steel *Č.4732* are possible in the whole axis of the work of the ripper within the limits of permissible stresses with respect to the stretching limit $R_{0.2}=750\ N/mm^2$ of steel *Č.4732* which is most commonly used as bolt material.

The results of the structural analysis of the adapter plate show that voltages $\sigma_{SVM}=410\ N/mm^2$ in the connection of the tractor link lugs are well above the permissible stress $\sigma_{doz}=280\ N/mm^2$ determined for the selected material of the panel *Č.1530* with the limit of expansion. $R_{0.2}=420\ N/mm^2$ taking the degree of certainty $\nu=1.5$. The deformations and stresses of the upper ripper levers are within the permissible limits.

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Contact address:
Vesna Jovanovic
University of Niš
Faculty of Mechanical engineering
18000 Niš
A. Medvedeva 14
E-mail: vesna.jovanovic@masfak.ni.ac.rs

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MODEL OF THE ELECTRO-PNEUMATIC FESTO MOTION TERMINAL

Vladislav BLAGOJEVIĆ [1]
Saša MILANOVIĆ [2]

[1)] *Faculty of Mechanical Engineering, Univercity of Niš*
[2)] *Faculty of Mechanical Engineering, Univercity of Niš*

Abstract

The Festo Motion Terminal is a system with high level of adaptability and flexibility. This system is in line with the philosophy of the Industry 4.0 and can be applied in many material handling processes which are parth of logistic processes in one industry. Terminal is realized by a bridge circuit that is made up of four 2/2-way valves that allows performing a wide range of conventional as well as proportional valve functions using a single terminal. This paper describes a detailed mathematical model of the Festo Motion Terminal which provides good basis for future pneumatic actuator control designing. The effects of nonlinear flow and air- compressibility were most carefully taken into consideration. At the end of the paper the properties of the proposed mathematical and simulink model of motion terminal have been verified by computer simulations.

Key words*: Pneumatics, Mathematical mode, Terminal, Control.*

1 INTRODUCTION

We are all witnesses of the fourth industrial revolution. It is known as the 4.0 industry. The fourth industrial revolution brings with it the inclination towards total automation of production and logistics, that is, to the production of completely independent of operator. 4.0 industry is expanding to the field of application of pneumatic systems, which has led to many intelligent components [1]. The Festo Motion Terminal is one such component that implements functions using programs in the form of motion applications. This component is very important and suitable in many handling processes in logistics. It enables replacement conventional as well as proportional pneumatic valves in actuator controlling and easy connection with internet, which is philosophy of 4.0 industry. One component replaces many other components. This is done using integrated, flexible and programmable processors, as well as the smart actuator technology within the system. The Festo Motion Terminal enables to execute a wide range of pneumatic motions and knowledge of mathematical model of terminal is very important.

Many authors dealt with the issue of designing the mathematical model of the pneumatic actuator system. Cameiro and Almeida [2] designed mathematical model of the pneumatic servo valve using artificial neural networks. Valdiero, Ritter, Rios and Rafikov [3] introduced fifth-order nonlinear mathematical model of the pneumatic actuator system with pneumatic servo valve. Harris, O'Donnell and Whelan [4] developed the complex mathematic model of entire pneumatic actuator system and servo valve model as well. Blagojević, Šešlija, Stojiljković and Dudić [5,6] developed the mathematical model of the pneumatic servo valve with by-pass valve. They improved the energy efficiency of such electro-pneumatic system. Nouri and Saudi [7] designed mathematical model of the 5/3-way proportional directional control valve. Pipan and Herakovic [8] analyzed the dependence of volume flow on pulse width modulation control signal through a fast-switching pneumatic valve.

The aim of the paper is to design a mathematical model of a smart actuator technology within the Festo Motion Terminal, which provides good basis for future control designing. Also, the Matlab simulink model of Festo Motion Termilan is introduced.

2 FESTO MOTION TERMINAL - SMART ACTUATOR TECHNOLOGY

In the Festo Motion Terminal, smart actuator technology is realized by a bridge circuit with integrated sensors that is made up of four 2/2-way valves in the form of piezo pilot and diaphragm poppet valves, Fig. 1. The valves are marked as 1.1, 1.2, 1.3 and 1.4, for actuator 1.0.

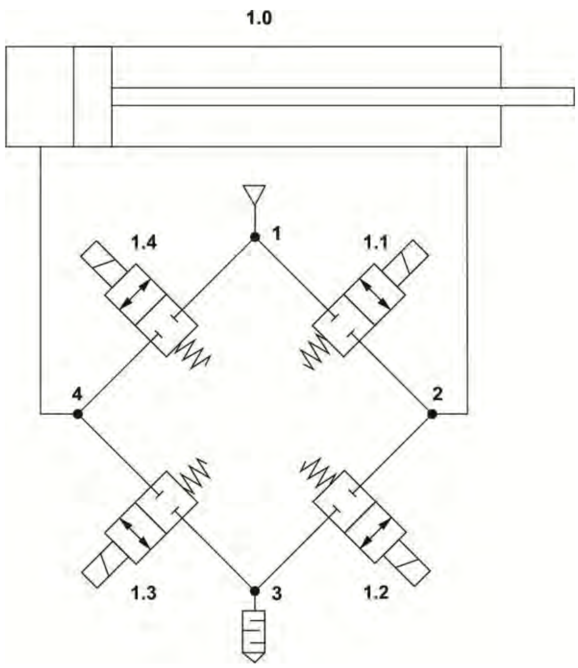

Fig. 1 *Bridge circuit with four 2/2-way valves*

The characteristic valves connection in the motion terminal enables realizing a wide range of different functions of the conventional valve's types, like 4/2-way and 4/3-way, Fig. 2.

Port 1 in the bridge circuit is always connected to the power supply with P_s pressure of compressed air that typically goes from 600 to 800 kPa, while the port 3 is connected to the atmosphere with pressure P_a equal to atmospheric pressure. Ports 2 and 4 are connected to the respective actuator chambers, which can be a cylinder, Fig. 1, semi rotary drive, pneumatic muscle or another pneumatic actuator.

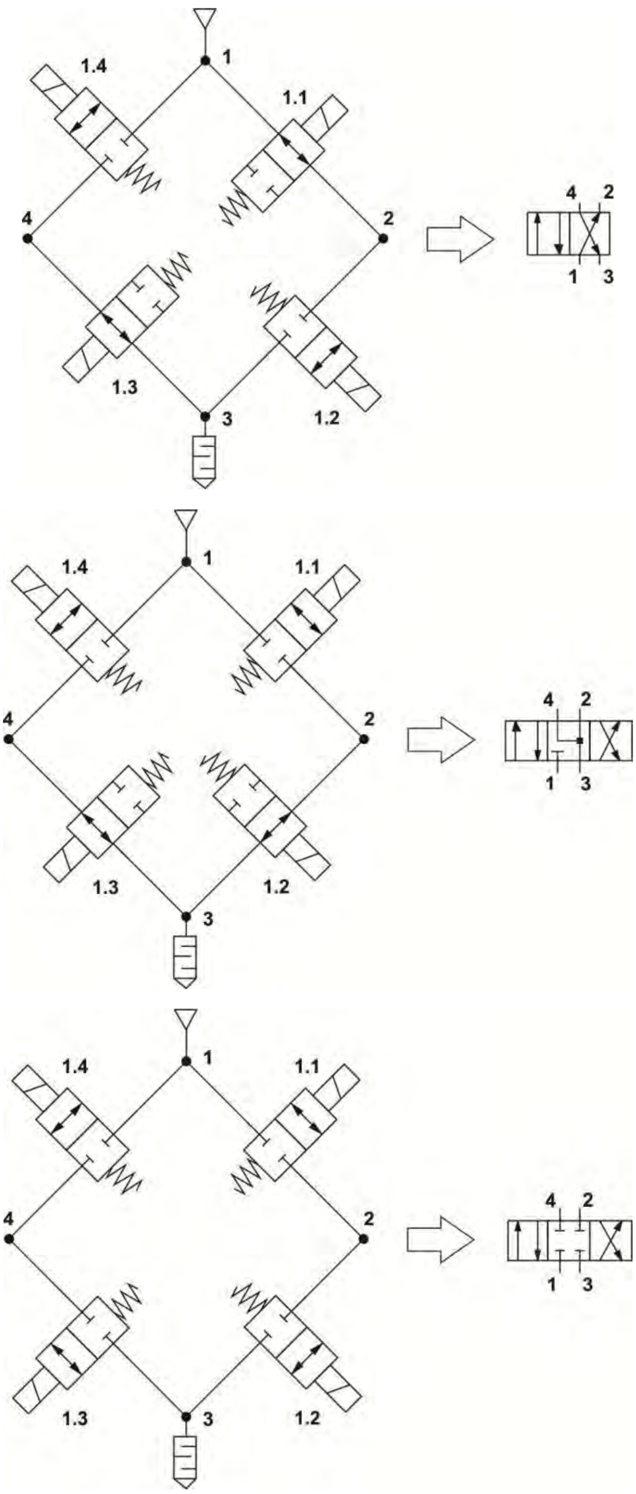

Fig. 2 *Characteristic valve connection types*

3 FESTO MOTION TERMINAL MATHEMATICAL MODEL

In order to design a mathematical model of the motion terminal, which consists of four 2/2-way valves, it is necessary to create a model of a single valve and later connect them all to the bridge circuit, as in Fig. 1.

The valve operates as an ON / OFF valve. When the activation signal is inducted to it, a certain amount of compressed air flows through it, or when there is no activation signal itself, the valve is in the non-activated position and compressed air doesn't flow through it.

Since the speed of the valve response is high, it is not necessary to consider the dynamics of mechanical and electrical parts of the valve, but only the dynamics of the mass flow of compressed air on the valve connection holes.

In a mass flow model under compressed air pressure through the valve connection hole, pressure drop on the hole is quite large, so that the mass flow must be treated as compressible and turbulent.

If the ratio of the downstream and the upstream pressure is such that it is less than the critical value (p_{cr}), the flow will reach the acoustic speed and will depend linearly of the upstream pressure. If this ratio is greater than critical value, the mass flow will depend nonlinearly on both the pressure, as can be seen in Eq.(1):

$$\dot{m}_v = c_f A_v \begin{cases} C_1 \dfrac{P_u}{\sqrt{T}} & , \quad \dfrac{P_d}{P_u} \le p_{cr}, \\ C_2 \dfrac{P_u}{\sqrt{T}} \left(\dfrac{P_d}{P_u}\right)^{1/\kappa} \sqrt{1-\left(\dfrac{P_d}{P_u}\right)^{\frac{\kappa-1}{\kappa}}} & , \quad \dfrac{P_d}{P_u} > p_{cr}, \end{cases} \tag{1}$$

where: $\dot{m}_v$ - mass flow under compressed air pressure through the valve connection hole, c_f - dimensionless coefficient, P_u and P_d - upstream and downstream compressed air pressure, A_v - effective valve port hole surface.

The effective valve port hole surface is expressed as:

$$A_v = A_v \,\mathrm{sgn}(u) \tag{2}$$

The coefficients C_1, C_2, and p_{cr} are constants that depend on the fluid, in this case the air (κ= 1.4),

$$\begin{aligned} C_1 &= \sqrt{\frac{\kappa}{R}\left(\frac{2}{\kappa+1}\right)^{\frac{\kappa+1}{\kappa-1}}} = 0.040418, \\ C_2 &= \sqrt{\frac{2\kappa}{R(\kappa-1)}} = 0.156174, \\ p_{cr} &= \left(\frac{2}{\kappa+1}\right)^{\frac{\kappa}{\kappa-1}} = 0.528. \end{aligned} \tag{3}$$

When four valves 2/2-way are connected in the form of a bridge, it is important to calculate the change in the mass flow at ports 2 and 4, Fig.1, as they are further connected to the chambers of the corresponding actuator. The change in the mass flow of compressed air on the port 2 is:

$$\dot{m}_{v2} = \dot{m}_{v1.1} - \dot{m}_{v1.2} \tag{4}$$

where: $\dot{m}_{v1.1}$ and $\dot{m}_{v1.2}$ are compressed air mass flow through valve 1.1 and 1.2, respectively, and they are expressed like Eq.(5) and Eq.(6), where: P_2 is the value of the compressed air pressure in the port 2, $A_{v1.1}$ and $A_{v1.2}$ are effective valve port hole surfaces for valves 1.1 and 1.2, respectively.

$$\dot{m}_{v1.1} = c_f A_{v1.1} \begin{cases} C_1 \dfrac{P_s}{\sqrt{T}} & , \dfrac{P_2}{P_s} \le p_{cr}, \\ C_2 \dfrac{P_s}{\sqrt{T}} \left(\dfrac{P_2}{P_s}\right)^{1/\kappa} \sqrt{1-\left(\dfrac{P_2}{P_s}\right)^{\frac{\kappa-1}{\kappa}}} & , \dfrac{P_2}{P_s} > p_{cr}, \end{cases} \tag{5}$$

$$\dot{m}_{v1.2} = c_f A_{v1.2} \begin{cases} C_1 \dfrac{P_2}{\sqrt{T}} & , \dfrac{P_a}{P_2} \le p_{cr}, \\ C_2 \dfrac{P_2}{\sqrt{T}} \left(\dfrac{P_a}{P_2}\right)^{1/\kappa} \sqrt{1-\left(\dfrac{P_a}{P_2}\right)^{\frac{\kappa-1}{\kappa}}} & , \dfrac{P_a}{P_2} > p_{cr}, \end{cases} \tag{6}$$

The change in the mass flow of compressed air on the port 4 is:

$$\dot{m}_{v4} = \dot{m}_{v1.4} - \dot{m}_{v1.3} \tag{7}$$

where: $\dot{m}_{v1.3}$ and $\dot{m}_{v1.4}$ are compressed air mass flow through valve 1.3 and 1.4, respectively, and they are expressed like:

$$\dot{m}_{v1.4} = c_f A_{v1.4} \begin{cases} C_1 \dfrac{P_s}{\sqrt{T}} & , \dfrac{P_4}{P_s} \le p_{cr}, \\ C_2 \dfrac{P_s}{\sqrt{T}} \left(\dfrac{P_4}{P_s}\right)^{1/\kappa} \sqrt{1-\left(\dfrac{P_4}{P_s}\right)^{\frac{\kappa-1}{\kappa}}} & , \dfrac{P_4}{P_s} > p_{cr}, \end{cases} \tag{8}$$

$$\dot{m}_{v1.3} = c_f A_{v1.3} \begin{cases} C_1 \dfrac{P_4}{\sqrt{T}} & , \dfrac{P_a}{P_4} \le p_{cr}, \\ C_2 \dfrac{P_4}{\sqrt{T}} \left(\dfrac{P_a}{P_4}\right)^{1/\kappa} \sqrt{1-\left(\dfrac{P_a}{P_4}\right)^{\frac{\kappa-1}{\kappa}}} & , \dfrac{P_a}{P_4} > p_{cr}, \end{cases} \tag{9}$$

where: P_4 is the value of the compressed air pressure in the port 4, $A_{v1.3}$ and $A_{v1.4}$ are effective valve port hole surfaces for valves 1.3 and 1.4, respectively.

Equations (4) and (7) shows that the compressed air mass flow has a positive sign for charging the actuator chamber and negative sign for discharging the actuator chamber.

It is important to highlight that simultaneously activations of valves 1.1 and 1.4 is forbidden.

4 FESTO MOTION TERMINAL SIMULINK MODEL

For design of an automatic control system it is important to previously create a mathematical model of the control object. The most important thing is to check the mathematical model itself before being applied to the real system. One of the best ways for checking the designed control of the system and mathematical model itself is usage of simulink model in Mathlab environment.

The simulink model of Festo Motion Terminal consists of four subsystems (subsys 1.1, subsys 1.2, subsys 1.3 and subsys 1.4) according to four 2/2-way valves, which are connected to the characteristic bridge circuit, Fig. 3.

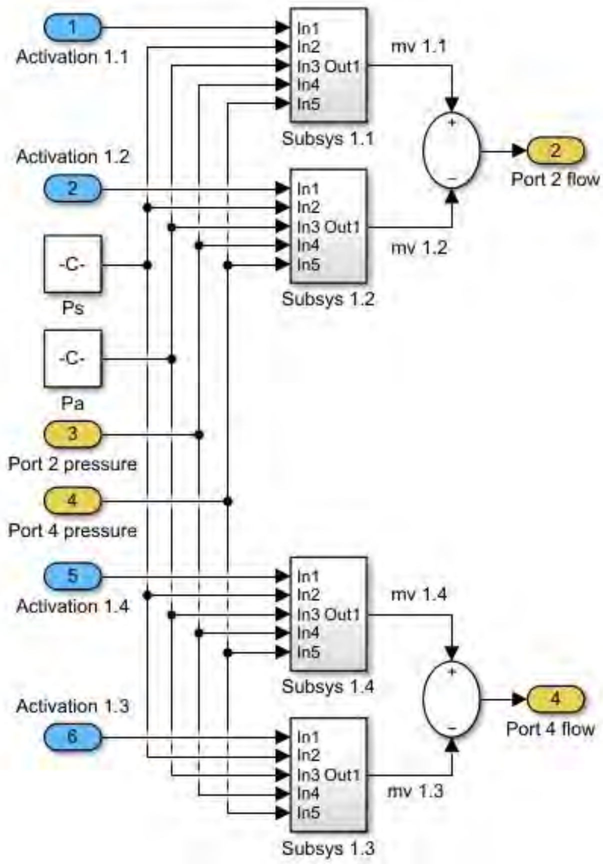

Fig. 3 *Simulink moddel*

The simulink subsystems are blocks with five inputs and one output. Inputs are on the left side of the Fig.3. Inputs are activation signals 1.1, 1.2, 1.3 and 1.4 colored by blue, port 2 pressure and port 4 pressure colored by yellow and pressure supply P_s and atmosferic pressure P_a colored by white. Outputs are port 2 flow and port 4 flow colored by yellow, on the right side of the Fig.3.

The simulink subsystems realize the functional relationship between inputs and compressed air mass flow through apropriate valve according to Eq.(1) and Eq.(2). The output signals from subsystems are: mv 1.1, mv 1.2, mv 1.3 and mv 1.4.

Port 2 flow and port 4 flow are compressed air flows through ports 2 and 4, Fig. 1, and they are product of substraction apropriate signals, like mv 1.1 and mv 1.2 for air flows through ports 2 and mv 1.3 and mv 1.4 for air flows through ports 4.

5 SIMULATION RESULTS

The properties of the proposed mathematical and Simulink model of Festo Motion Terminal have been verified by computer simulations by Matlab. The simulations were performed with 600 kPa compressed air supply P_a, in order to record the compressed air mass flow in port 2 and port 4, when the cylinder operate, Fig. 1. Simulation parameters are: T=293K, effective port hole surfaces for all valves are A_v=0.00071 and coefficient C_f=0.025. Valves marked 1.4 and 1.2 were activated; while the valves marked 1.1 and 1.3 were not activated.

Under those conditions, compressed air mass flows in port 2 and port 4, were changing in the expected way, Fig.4, and Fig.5.

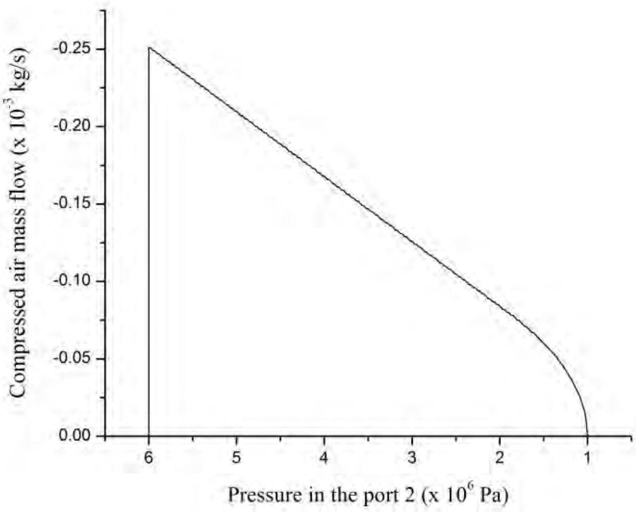

Fig. 4 *Compressed air mass flow in the port 2*

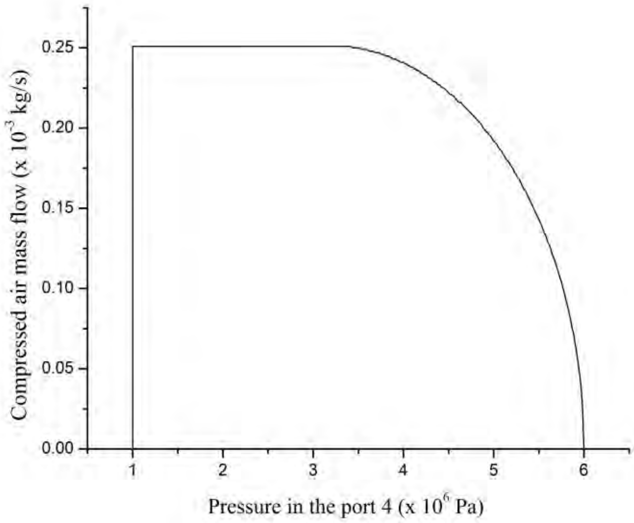

Fig. 5 *Compressed air mass flow in the port 4*

Compressed air mass flow in the port 2, Fig. 4, has a steady decrease due to a continuous drop in pressure, which represents the upstream pressure.

In the port 4, compressed air mass flow has constant value and the flow reaches the acoustic speed, until the ratio of the pressure in the port 4 and the pressure supply became greater than critical value p_{cr}.

CONCLUSION

The Festo Motion Terminal is a component that implements functions using programs in the form of motion applications. This component is very important and suitable in many handling processes in logistics and allows performing a wide range of conventional as well as proportional valve functions.

In this paper, a mathematical and simulink model of the Festo Motion Terminal that is realized by a bridge circuit with four 2/2-way valves is described. The dynamics of the mass flow of compressed air on the valve connection holes are described. The compressed air mass flow was treated as compressible and turbulent.

Simulation results shows that mathematical and simulink model gives a good basis for further design of pneumatic actuators control.

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Contact address:
Vladislav Blagojević
University of Niš
Faculty of Mechanical engineering
18000 Niš
A. Medvedeva 14
E-mail: vlada@masfak.ni.ac.rs

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IDENTIFYING RELEVANT INDICATORS FOR COST-EFFECTIVE MAINTENANCE IN COAL-FIRED THERMAL POWER PLANTS

***Daniela MLADENOVSKA*[1]**
***Ana M. LAZAREVSKA*[2]**

[1)] Technical Faculty, University Mother Teresa Skopje
[2)] Faculty of Mechanical Engineering, University ss. Cyril and Methodius Skopje

Abstract

Power plants maintenance embeds a variety of operations and activities directed towards plant's operability, risk prevention/reduction, reliability and availability, which significantly affect plants' Life Cycle Costs (LCC). The operating ratio value of a power plant, as an indicator of its profitability, is strongly influenced by the implemented cost-effective maintenance. Hence, this work focuses on analyzing the maintenance costs status-quo in the largest coal-fired power plant in Macedonia and via utilizing systems analysis (incl. spatial and temporal aspects) and multi-criteria decision analysis (MCDA), it discerns the relevant set of attributes and indicators towards creating a cost-effective maintenance policy .The noted spatial and temporal complexity and correlation of the identified attributes seeks a multidimensional solution to the problem.

Key words*: maintenance, logistics, stock inventory, cost-effectiveness, power plants, attributes.*

1 INTRODUCTION

Maintenance is one of the crucial operations especially concerning capital-intensive production systems [1,2]. Regarding electricity production systems, the importance of maintenance is even more significant, since power plants contain a set of highly sophisticated subsystems which require the highest possible level of availability and reliability [3]. The obsolescence of these subsystems increases risk of unavailability of the power plant. This situation becomes particularly vulnerable in terms of equipment in coal-fired thermal power plants (TPP), due to the influence of coal particles abrasion, high steam parameters, as well as used chemicals for water treatment etc. Furthermore, in most coal-fired TPPs, the equipment operates close to its rated capacity [4]. Therefore, any failures, especially catastrophic ones, can result in reducing their reliability.

Maintenance is defined as a process consisting of **technical**, **administrative** and **managerial** activities carried out over the life-time of the equipment, in order to maintain overall asset value. The activities include planning, coordination, finance, and operations focused towards achieving optimal levels of reliability, availability, productivity and market value. Since, maintenance is an attempt to prevent equipment or various system components from damage and performance degradation caused by operation, and to provide equipment working properly in accordance with its function [5], it embeds a set of actions required to be taken continuously, in order to achieve and ensure reliable production.

There are two types of maintenance – **corrective** and **preventive**. Corrective maintenance usually is performed after a breakdown has occurred, while preventive maintenance is performed to reduce failure opportunities of the respective system. On the other hand, mainly due to budget constraints, it is impossible to apply all maintenance actions over the entire equipment as maybe originally and optimally desired or planned. Thus, the main goal of cost-effective maintenance operations should provide balance between reliability and cost [6]. Having in consideration that power plants are part of the national critical (energy) infrastructure, the problem with cost-effective management becomes even more important, not only in terms of economy, but also concerning social well-being and national security [7].

According to Fernando and Gilberto (2009) [8], the availability of a power generating system depends on the reliability of each of its generation units and the corresponding maintenance policy. Maintenance policy does not only affect repair time but as well reliability of the parts. Sénéhal (2018) [9] introduces performance indicators nomenclatures for decision-making in sustainable conditions based maintenance. Parida (2007) [10] identifies and develops maintenance performance indicators for a mineral processing plant, while Ruqun Wu et al. (2017) [11], utilize the spatial and temporal dynamics for Life-cycle sustainability assessment in addressing environmental problems.

The focus of this paper sets on identifying relevant indicators for cost-effective maintenance in coal fired TPPs, having in prospect not only direct/explicit economic indicators, but as well the costs embedded in other "non-economic" categories. It considers spatial and temporal aspects of maintenance related Life Cycle Costs (LCC). The identified attributes and indicators could help decision-makers and maintenance managers in preparing a sound and cost-effective maintenance strategy and policies, that will affect not only direct maintenance operations costs, but as well shall examine/investigate aspects indirectly linked with maintenance such as: staff training, inventory management, environmental protection, energy efficiency and work safety principles. A long-term analysis and management of all related aspects is among are crucial for cost-effective maintenance.

2 COST-EFECTIVE MAINTENANCE

Power utilities cause immense annual maintenance costs. Maintenance outages of generating units in power plants affect the system operation reliability and increase production cost of the generating facilities.
In accordance with Al-Najjar (1996) [12], Sweden spent about $23 \cdot 10^9$ USD annually just for maintenance and safety. Due to improper maintenance activities and maintenance mismanagement, the maintenance costs could often exceed the value of the equipment. Furthermore, the research of Mobley (1990) [13], shows that about 28% of the total cost in a final product is due to maintenance activities in an industry. Other than that, the Department of Trade and Industry in the UK [14] discovered that improper and unsafe maintenance burdens the UK industry with around USD $1.95 \cdot 10^9$ annually.
By means of effective maintenance, a system can improve its productivity, extend its life and reduce its negative impact on humans and the environment [15]. Therefore, a cost-effective maintenance must determine scope, type and timing of maintenance activities, in order to balance between the expected savings through maintenance and plant's overall direct and indirect costs [15].
With reference to electric power systems, it is difficult to estimate the actual economic impact of maintenance outages due to the uncertainty of variables such as electricity demand, electricity prices and power generation. Maintenance planning and scheduling is further complicated by the separation of decisions in departments with conflicting objectives. Namely, whereas the maintenance department aims to perform its activities on a regular basis, the production department wants to avoid loss of production due to maintenance downtime [16].
The maintenance optimization for thermal power units is a complex and multifold problem that has been widely studied and analyzed by using both traditional as well as modern techniques. The maintenance scheduling of thermal power units should be optimized regarding the objective function under a series of constraints. There are generally two categories of objectives in the maintenance scheduling problem: based on costs [17,18] or profit [19,20] and based on reliability [21,22]. The most common objective based on costs is to minimize total operating costs over a planning period [23].
Many studies indicated that although required, most of the facilities did not prepare resources needed to perform equipment maintenance to keep availability of production [5]. Maintenance organization should be able to assist the management in achieving its operational performance objectives. Lack in technicians' skills and knowledge, will result in high costs in maintenance management and will affect the organization performance. In order to support organizations to work properly, technicians with the necessary skills and knowledge are required to meet organizations maintenance needs [24]. Thus, from the perspective of a cost-effective maintenance the availability of in-house skilled workers is a very important issue. Armstrong (1971) [25] said that "manpower refers to human resources used in carrying out jobs in any organization". This Report of the conference board on manpower planning and evolving systems in 1971 further defined manpower planning as a process intended to assure an organization that it will have the proper number of adequately qualified and motivated employees in its workforce at some specific future time to carry on the work that would then have to be done.
Operating ratio (OR) is a frequently used indicator to assess power plants cost-efficiency. Maintenance costs represent a significant share of the total expenditures included in the OR, Therefore, the focus in this paper is set on identifying relevant attributes that discern inefficient and inadequate from cost-efficient and sustainable maintenance, thus contributing towards the overall condition and proper and sustainable operation of a power plant. In addition, it enables the analysis of other efficiency indicators, such as load factor and capacity factor. The OR indicator highlights where quantity and quality of power supply are problematic; both directly related to the condition of the sector assets. It also points to cases, in which non-operational assets might create fiscal problems [26].

3 METHODOLOGY

3.1. Operating ratio (OR) as a cost-effectiveness indicator

OR is a clear and simple indicator of the power plants cost-effectiveness and profitability. It is defined as a share (in percentage) of operating expenses (such as fuel, operation and maintenance, depreciation and staff/personnel expenses) in the total revenue. OR shows the management efficiency of a power generating company by comparing operating expenses to net sales (revenue). Meaning, the smaller the OR, the greater margin an organization possesses to generate profit. Conversely, greater OR, the lower margin to generate profit. The formula for calculating OR therefore is [26]:

$$OR(\%) = \frac{\text{Operating\_expenses}}{\text{Revenues\_or\_sales}} \cdot 100 \qquad (1)$$

In brief, operating ratios in the range of 75% and 85% or thereabouts, may be considered as desirable, as they indicate company ability to generate funds from the company operations and thus produce revenue for future development and increased capacity [26]. The consolidated operating ratio for Électricité de France (EDF) which produces 28.6% electricity from coal, and 53% from nuclear power, was 90% for 2013 and 92% for 2014. As per Enel group where coal contributes with 18% in the energy mix, OR was 78.8% for 2013 and 79.2% for 2014. In China Datang Corporation (CDC), where coal participated with 80.71% (in 2015), the OR was 62%. Thus, since the OR at all these companies is below the 100%-threshold (denoting no profit margin), all of them possess a margin to make profit.
Within operational costs, there are many factors that impact operational efficiency (and OR) of a power generating company. These include cost of fuel, staff/personnel, operation and maintenance (O&M) and depreciation (the higher these factors are the higher the operating ratio and the lower the operational efficiency). Coal has long been the leader on the power generation market. In the absence of high costs for carbon emissions, its strong financial

advantages shall continue to provide coal competitiveness over other types of fuels/energy sources. Even though, O&M costs are not significantly low for coal, since the cheapest coal-fired technology - subcritical plants start with O&M costs of $43 per kW [27].

3.2. Multi-criteria decision analysis (MCDA)

Maintenance cost-effectiveness depends on different, often directly incomparable and even conflicting aspects/requirements, while adequate solution(s) requires its analysis over the entire supply chain in space and time. [11,28] The basic procedures for combining, comparing and addressing conflicting aspect/requirements that intrinsically are not comparable are covered by Saaty (1980), Goicoechea and Duckstein (1982) etc., while their solution is offered via introducing multi-criteria decision analysis (MCDA) [29,30]. MCDA is the set of methods and tools providing a mathematical methodology that incorporates preferences/opinions of decision-makers, as well as, problem relevant information (indicators), in order to select the best solution(s) for the analyzed problem and thus to deliver a more logical and scientifically justified decision [31].

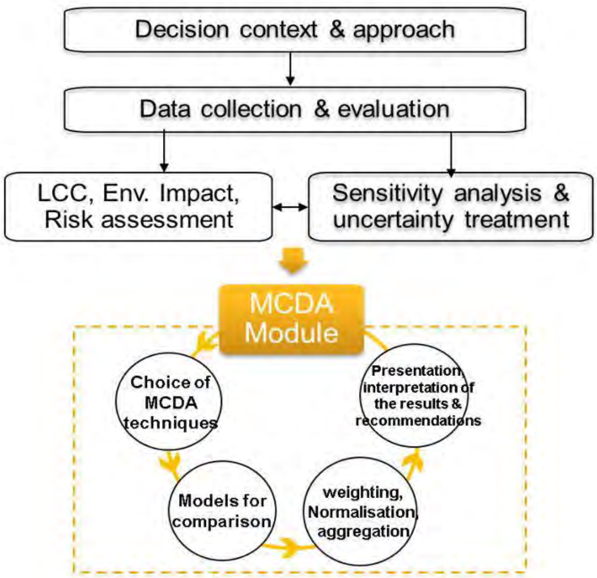

***Fig. 1** Generic framework for MCDA workflow [31]*

The multifold character of the problem elaborated herein requires a MCDA approach in the process of finding an optimal (set of) solution(s). Hence, this paper deals with a comprehensive frame for problem definition, not only regarding multiple indicators that affect it, but also in terms of multidimensionality (both spatial and temporal boundaries) of the problem and the possible interdependencies between aggregate indicators. Such an approach facilitates decision-makers to deliver optimal maintenance actions, because they are offered insight of the indicators reflecting the maintenance history (repair history and inspection history), the most frequent outages causes, resource efficiency, as well as the level of equipment degradation during time. Further, this approach offers insight to evaluate spatial aspects of the types of equipment failures and causes, thus identifying the most vulnerable locations throughout the installation/plant/process. This can be very useful in assessing and comparing the total LCC for planned and purchased new equipment or their refurbishment. The main constrains the herein presented problem are budget limitations and reliability vs. risk reduction.

4 IDENTIFYING INDICATORS FOR COST-EFFECTIVE MAINTENANCE IN COAL-FIRED THERMAL POWER PLANTS

4.1. Thermal Power Plant Bitola status-quo

Thermal Power Plant Bitola is the largest power generation capacity in Macedonia. It uses lignite from the nearby open pit mine, and consists of 3 subcritical units each 233MW of installed capacity. As presented in Table 1, the operating ratio values of TPP Bitola over time are significantly above the threshold, indicating high expenditures and/or low capacity factors of the facilities which further result in lower production rates. Over-employment, resulting in significant share of wages costs in the total expenditures, is also noted as a problem. Another identified issue is the price policy regarding regulated electricity producers. Moreover, certain studies [32,33,34] pointed out the existence of hidden political influence related to setting regulated prices for electricity production, as a tool to affect social component especially trough cross-subsidization between industry and households. Table 1 summarizes values of operating ratios, maintenance costs and wages in the 2012-2016 period at the TPP Bitola.

Table 1 Values on operating ratio and other indicators for TPP Bitola in the period 2012-2016[1]

	2012	2013	2014	2015	2016	Average
OR (%)	103	119	124	134	123	120
Outsourced maintenance costs share in total expenditures (%)	26	30	26	33	23	29
Wages share in total expenditures (%)	21	21	21	20	26	21

The data shows that TPP Bitola possesses no margin to make profit; on the contrary, it actually generates losses. Thus, the focus of the decision-makers should be set not only on the cost-effective maintenance, but also in the area of a solid electricity pricing methodology, independence of the energy regulatory body, as well as on improvement of the plant capacity factor and managing the over-employment problem. As for the O&M costs per installed kW, based on the O&M data for 2017, TPP Bitola has a 3.8

[1] http://www.elem.com.mk/?page_id=530 (accessed on 11.10.2019)

times higher value compared to the referent value for subcritical TPPs [27].

The maintenance cost-efficiency should be mainly focused on the TPPs facilities that are most vulnerable to forced outages, both through the perspective of outages costs and duration. Table 2 is a summary of those values for TPP Bitola, based on the outages history for 2015. Thus, the plant facility with highest number of outages as well as the longest cumulative outage duration is considered as the most decisive for the TPP reliability and availability. Therefore, the proposed maintenance strategies and plant maintenance policy should be in particularly focused on those facilities, including long term assets value, staff training, spare parts inventory stock etc.

Table 2 Number and duration of forced outages in TPP Bitola in 2015

	Number of outages (-)	Duration (h)
Boilers	34	2393
Steam pipelines	2	39
Steam turbines	6	2321.7
Feed water system	5	235.9
Flue gases fans	2	40.3
Generators	4	323.8
Chemical water treatment plant	3	407.5
6 kV switchyard	1	17.5
Uninterrupted power supply (UPS)	1	13.4
400kV substation	1	10.3

The problem of establishing cost-effective maintenance practices gains in complexity when it comes to public owned power plants with significant political influence, mismanagement and lack of proper maintenance management strategy [34]. Such circumstances lead towards simultaneously increasing of the maintenance services costs, wages costs, and inventory stock, while at the same time the equipment reliability and the skills of the in-house workforce are neglected.

4.2. Spatial and temporal indicators for cost-effective maintenance

Having in perspective that cost-effective maintenance embeds different facilities over their entire life-cycle, as well as different management areas directly or indirectly connected with maintenance operations, identifying indicators relevant for cost-effective maintenance is not one dimensional. Namely, both spatial (location in the facility/system) and temporal aspects of the costs must be taken into account. In particular, spatial aspects embed different facilities where maintenance is deployed, as well as different departments that should be in close cooperation on a daily basis, while temporal aspects are related with short/medium/long term planning and resources management, and their contribution is especially visible in maintaining the TPP reliability by improving assets value as well as stable structure, training, skills, education and quality of the in–house staff. Relevant indicators, in view of spatial (S) and temporal (T) aspects, are presented on Figure 2. The structure on Figure 2 shows significant interdependence among spatially and temporally related indicators. However, although a significant part of the identified indicators are characterized both with spatial and temporal features, the context of their analysis is different. The herein presented structure does not limit to the usual hierarchical approach, since among some of the indicators no clear subordination exists, bur on the contrary, correlation and interdependence are significant. One of the maintenance tasks should be the commitment for at least as possible waste generation and energy efficient operation. Hence, a comprehensive approach as presented herein, in analyses of both groups of indicators (spatial and temporal) lead towards a cost-effective and sustainable maintenance practice, resulting in optimal reliability and availability of the analyzed plant.

5 RESULTS AND DISCUSION

Both spatial and temporal approach in the LCC of maintenance actions, contribute to a more comprehensive perception in planning cost-effective maintenance practices. By identifying correspondent attributes and indicators, it becomes possible to set priorities' and improve plant's condition regarding crucial departments affecting cost-effectiveness, reliability and availability. While spatially defined attributes relate to specific facilities and areas of operation, the temporal ones associate to long-term planning, implementation of new technologies as well as human resources training and education. Having the current national status-quo, political influences and legislation issues are intertwined throughout all groups of attributes. It could be noted that political influence (reflected via rule of law and governance) has significant impact in investments related decision making, human resources structure, public procurement, etc. Although not visible on first glance, solid human resources policy and permanent staff training and education, in particular in terms of specific sector related skills, are among the most important influencing matters/issues. Having in mind the specific circumstances concerning political influence in public owned energy utilities, resulting in frequent changes of the posts and lack of criteria for appointments on managerial positions, the power assets in the region are still far from purely cost-effective and scientifically based maintenance decisions. Moreover, the cooperation and knowledge sharing both intra- and inter-departments contribute significantly in the cost-effective maintenance. As it could be noted, the majority of indicators presented in this paper, appear both in the spatial and temporal plane. Thus, one of the most significant issues that require further analysis is the cross sectional view of the two (spatial and temporal) indicators. It implies that most of the indicators should not be analyzed in a simple hierarchical or one-dimensional way, but rather through a multilayer and correlating prism.

6 CONCLUSION

The problem of cost-effective maintenance in coal-fired TPPs has a long history and requires a comprehensive approach. The problem is difficult to manage due to the fact

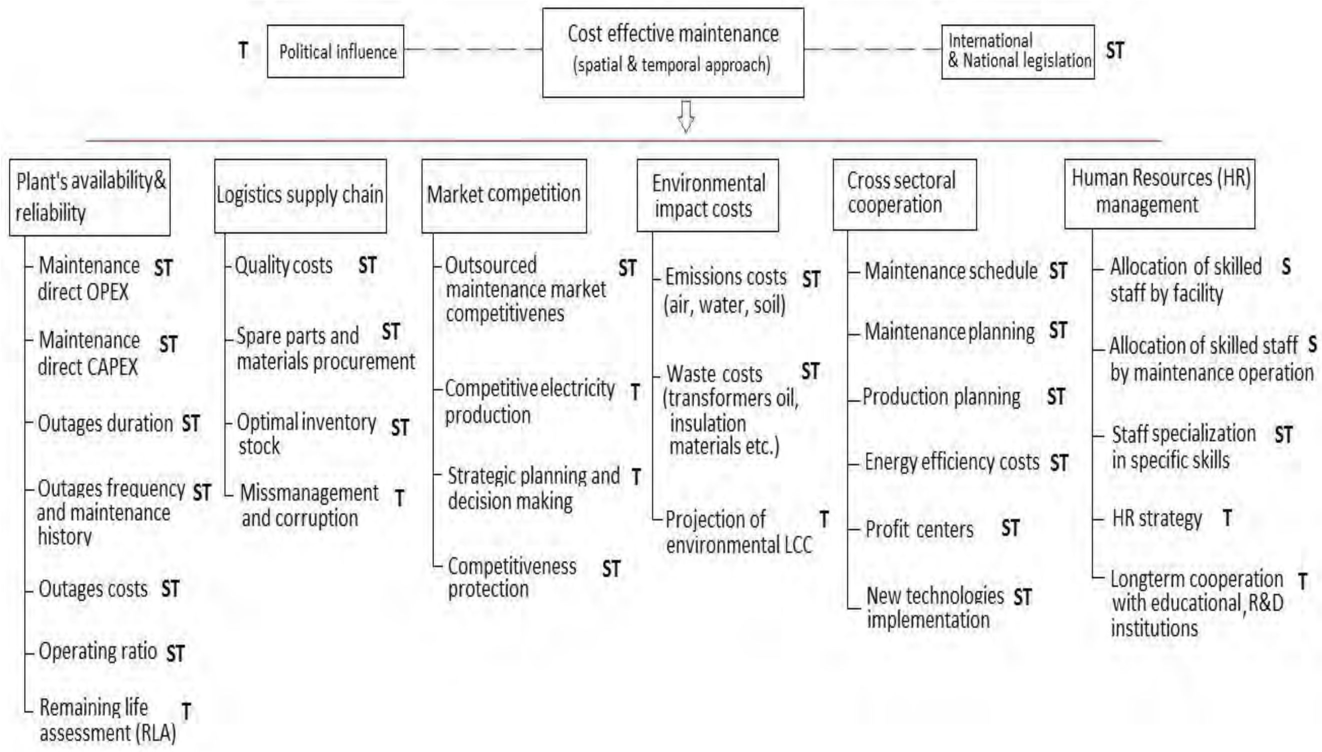

Fig. 2 *Spatial and temporal indicators for cost-effective maintenance*

that TPPs consist of a number of facilities spread over a large area, they embed various processes and employ significant workforce. Moreover, maintenance activities and costs must be analyzed over the entire life-time of the equipment, in order to provide temporal sustainability. Traditionally, the main task of the management is focused on realization of its production and procurement plans within the annual budget. Hence, such practices do not contribute much towards reliable and sustainable cost-effective maintenance. The problem is even more evident in publically owned utilities where there are additional affecting constrains: lack of long term strategy related with new employments, lack of trained and competitive work force, lack of investments in energy efficiency improvement.

An additional barrier regarding limited and uncompetitive markets (as it is a case in the region of Western Balkans), is the reason that the outsourced maintenance comes with significantly higher prices due to several issues include lack of market competitiveness for specialized works, significant political influence, lack of competences among the management, corruption and bad governance, etc. Hence, these circumstances showed that some of the typical and usual indicators vis-à-vis electricity generation companies' profitability (operational ratio) are not applicable in terms of the herein analyzed TPP. This paper suggests an approach that could assist in identifying different influences related to cost-effective maintenance that could assist the decision makers in development of proper cost-effective maintenance strategy. Introducing mathematically based and software supported decision making could be beneficial in improving the situation.

ABREVIATIONS AND SYMBOLS

LCC	Life Cycle Costs
TPP	Thermal Power Plant
OR	Operating Ratio
O&M	Operation and Maintenance
MCDA	Multi Criteria Decision Analysis
UPS	Uninterrupted Power Supply
S	Spatial
T	Temporal
HR	Human Resources
RLA	Remaining Life Assessment

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Contact address:
Daniela Mladenovska
Technical Faculty, University Mother Teresa
Skopje

UNIVERSITY OF NIS FACULTY OF MECHANICAL ENGINEERING

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MULTI-CRITERIA OPTIMAL SYNTHESIS OF THE LOADER MANIPULATOR DRIVE MECHANISMS USING THE GENETIC ALGORITHM

Jovan PAVLOVIĆ[1]
Dragoslav JANOŠEVIĆ[1]
Vesna JOVANOVIĆ[1]
Nikola PETROVIĆ[1]

[1] *Department for Material Handling Systems and Logistics, Faculty of Mechanical Engineering, University of Niš*

Abstract

The paper presents the procedure of optimal synthesis of the manipulator drive mechanisms with Z kinematics of the loader using a genetic algorithm. The objective functions of the optimization are: minimal change of bucket angle during material transfer operation and maximum transfer function of manipulator drive mechanisms. Loader performance parameters are specified as optimization constraints, and the optimization area is the zone of possible positions of the joints of the kinematic chain of the Z kinematics manipulator. As an example, the results of the optimal synthesis of loaders drive mechanisms using the genetic algorithm as a tool for solving global extremum problems are given.

Key words: *optimal synthesis, genetic algorithm, loader mechanism*

1 INTRODUCTION

Loaders are mobile machines whose basic function (Fig. 1) is the cyclical transport of material, which consists of the following operations: loading (digging), transfer, unloading of material, and returning to a new position of loading. Various configurations of the kinematic chains of the loader have been developed to perform the basic functions. Concepts with the drive mechanisms of the Z kinematics manipulator and parallelogram kinematics have been distinguished among them.

Previous research of loaders has mainly concerned the optimization of the manipulator drive mechanisms.

Several authors have been concerned with optimizing the drive mechanisms of loader manipulators. In paper [1], a multi-criteria optimization of the drive mechanisms of a parallelogram manipulator is presented. The sensitivity method shows which optimization variables most influence the objective function. Finally, the multi-criteria optimization problem is translated into a single-criterion optimization problem using the fuzzy set theory developed in the paper.

A dynamic mathematical model of the Z - kinematics manipulator was developed in paper [2] for optimization of the drive mechanisms of the manipulator with the aim of minimizing the power consumption of the drive mechanisms during the material loading operation.

The paper [3] presents a mathematical model of a loader on the basis of which multi-criteria optimization of the manipulator drive mechanisms was performed using a genetic algorithm. The mathematical model for the optimal synthesis of the drive mechanisms of the loader manipulator in this paper is determined by nonlinear equations with weighted multi-objective optimization, which is subject to a set of defined constraints given in the form of inequality.

2 OPTIMAL SYNTHESIS OF THE MANIPULATOR DRIVE MECHANISMS

In order to solve the optimal synthesis of the loader drive mechanisms, this paper defines the mathematical model of the loader, in the absolute coordinate system *OXYZ*, a four-member configuration of the kinematic chain with the rear support-moving member L_1 (Fig. 1), the front support-moving member L_2 connected by a rotational joint with the vertical axis O_2 and the manipulator with: arm L_3 and bucket L_4. The members of the loader kinematic chain are defined in the local $O_ix_iy_iz_i$ coordinate systems.

The manipulator's arm is connected with the O_3 horizontal rotational joint (Fig. 2) with the front support-moving L_2 and the bucket L_4 with the rotational joint O_4 for the top of the arm.

The penetration of the bucket cutting edge through the manipulator plane is the center of the cutting edge of the bucket.

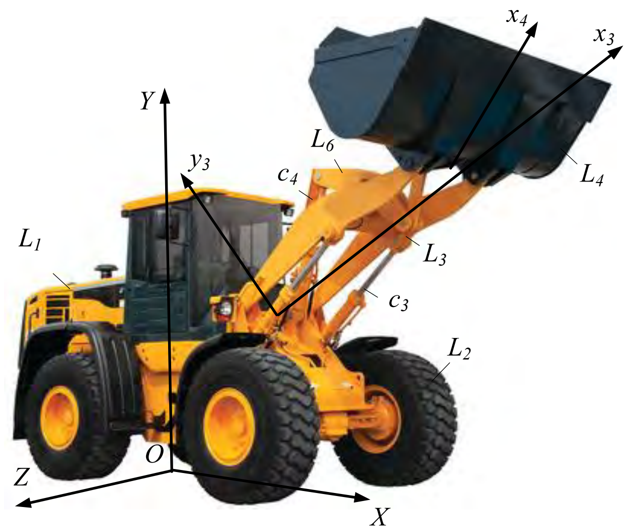

Fig. 1 Wheel loaders

The drive mechanism of the manipulator consists of: drive mechanism of the arm and the drive mechanism of the bucket. The actuator of the boom drive mechanism consists of two bi-directional hydraulic cylinders c_3 connected directly to the front support-moving member and the arm.
The drive mechanism of the bucket constructed by two bi-directional hydraulic cylinders c_4 as actuators, the two-arm lever L_6, the lever L_5 and the bucket L_4 in the form of *Z* kinematics, apropos, four bar linkage mechanism [4].
The optimal synthesis given in this paper relates to the optimization of the joint position coordinates and kinematic lengths of the manipulator drive mechanisms using a genetic algorithm.
The optimal synthesis of the manipulator drive mechanisms is seen as a multi-criteria optimization, which is generally defined as finding the vector:

$$X = [x_1, x_2, ..., x_n]^T \tag{1}$$

to optimize objective functions:

$$min/\ max \quad F(X) = [f_1(X), f_2(X), ..., f_k(X)]^T \tag{2}$$

subject to inequality constraints *m*:

$$g_i(X) \leq 0, \quad i=1,...,m \tag{3}$$

and equality constraints *h*:

$$h_j(X) = 0, \quad j=1,...,p \tag{4}$$

where: *X* is a vector of optimization variables, *F*(*X*) is a vector of objective functions.

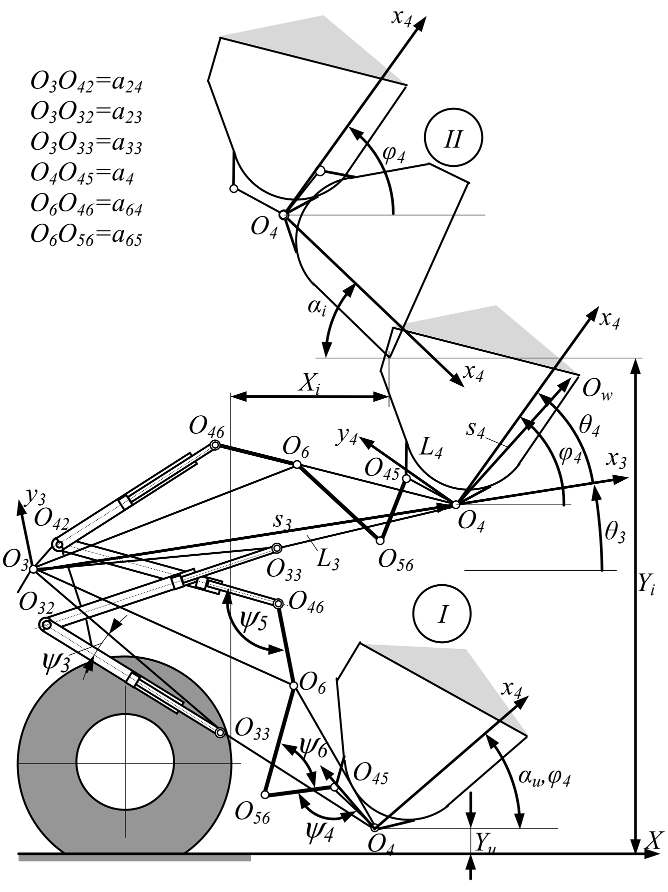

Fig. 2 Different positions of Z kinematcs manipulator

2.1. Objectiv functions

Within the multi-criteria optimization of the manipulator drive mechanisms of the loader, the following objective functions are defined:

- minimal change of the bucket angle during material transfer,
- maximum normalized transfer function of the arm drive mechanism.
- maximum normalized transfer function of the bucket drive mechanism.

Minimum change in bucket angle when the material is transferring. - For *Z* kinematics loader manipulators equi-pped with bucket shaped tools, it is very important when the bucket is lifting, from the loading position, and the bucket achieves the rotation angle α_u (Fig. 2) to the unloading position, to keep back angle of the bucket at the same angle with the horizontal plane of the support surface. This feature of the bucket drive mechanism prevents the loaded material from spilling over, where only the piston rods of the arm hydraulic cylinders are pulled out, while the bucket hydraulic cylinder do not change the length that they had at the beginning of lifting.

This makes it easier to operate as only a single command (to extract the boom hydraulic cylinder) can be used to lift the full bucket without spilling the loaded material.
The role of the relative rotation (correction) of the tool around the tip of the arm in order to maintain the desired position of the tool (bucket), when moving only the arm, is played by two four bar linkages: $O_3O_{24}O_{46}O_{36}$ and $O_{36}O_{65}O_{45}O_{34}$ (Fig. 2). Through them the dependent movement of the bucket drive mechanism is made by changing the stroke of the boom cylinder.
The first objectiv function f_1 of the optimization relates to the maintenance of the back angle of the bucket during the transfer of the loaded material and is defined as the minimum deviation of the bucket back angle φ_4 from the given angle α_u of bucket back angle at the end of the loading operation (Fig. 2):

$$f_1 = min(|\varphi_{4\,max} - \alpha_u| + |\varphi_{4\,min} - \alpha_u|) \tag{5}$$

where: φ_{4max}, φ_{4min} - maximum and minimum value of the bucket back angle in the range of motion when material is transferring.
The back angle of the spoon φ4 is determined in relation to the horizontal support surface:

$$\varphi_4 = \theta_3 + \theta_4 \tag{6}$$

where: θ_3 - the angle of the boom position relative to the local coordinate system of support moving member, θ_4 - bucket position angle with respect to the local coordinate system of the arm at the unchanged length that the bucket hydraulic cylinder has at the end of the loading operation.
The second objectiv function is transformed into a norma-lized objective function:

$$e_1 = \frac{f_1(\theta_3, \theta_4)}{max[f_1(\theta_3, \theta_4)]} \leq 1 \tag{7}$$

Maximum normalized transfer function of the arm drive mechanism.- Variable normalized transfer function r_{c3n} of the arm drive mechanism depends on the angle of the arm position θ_3 and is determined (Fig. 2):

$$r_{c3n}(\theta_3) = \frac{a_{33}}{a_{23}} \sin\psi_3 \le 1 \tag{8}$$

The second objective function f_2 is expressed as the maximum mean value r_{c3ns} of the normalized transfer function of the arm drive mechanism in the range of the manipulator motion:

$$f_2 = max(r_{c3ns}) \tag{9}$$

Maximum normalized transfer function of the bucket drive mechanism.- The variable normalized transfer function r_{c4n} of the bucket drive mechanism depends on the bucket position angles θ_4 and the arm θ_3, or the angles ψ_4, ψ_5, ψ_6 of the relative position of the lever position of bucket Z mechanism determined by the equation (Fig. 2):

$$r_{c4n}(\theta_3, \theta_4) = \frac{\sin\psi_5 \cdot \sin\psi_4}{\sin\psi_6} \le 1 \tag{10}$$

The third objective function f_3 is expressed as the maximum of the mean value r_{c4sn} of the normalized transfer function of the bucket drive mechanism in the range of manipulator motion:

$$f_3 = max(r_{c4sn}) \tag{11}$$

which, for the purposes of multi-criteria optimization by genetic algorithm, have been translated into a minimum of negative values of the transfer function of the drive mechanisms:

$$e_2 = min(-f_2) \tag{12}$$

$$e_3 = min(-f_3) \tag{13}$$

2.2. Optimization constraints and variables

The synthesis procedure begins with the requirements that the loader manipulator mechanism must fulfill. They are given in the form of a set of parameters (Fig.2):

$$P_{uk} = \{ L_1, L_2, s_3, s_4, Y_k, Y_u, \alpha_u, X_i, Y_i, \alpha_i \} \tag{14}$$

where: L_1, L_2 – parameters of the rear and front support-moving member of the kinematic chain, s_3 – kinematic length of the arm, s_4 – kinematic length of the bucket, Y_k – digging depth, Y_u – loading height, α_u – bucket angle at end of loading operation, X_i – horizontal reach of the bucket during unloading, Y_i – vertical reach of the bucket during unloading, α_i – bucket unloading angle.
Starting from the given kinematic lengths of the arm s_3 and the bucket s_4, as well as the given coordinates of the position of the joint O_3 where the arm is connected, the optimal synthesis of the drive mechanisms of the manipulator consists of determining the vector of variable optimizations [4]:

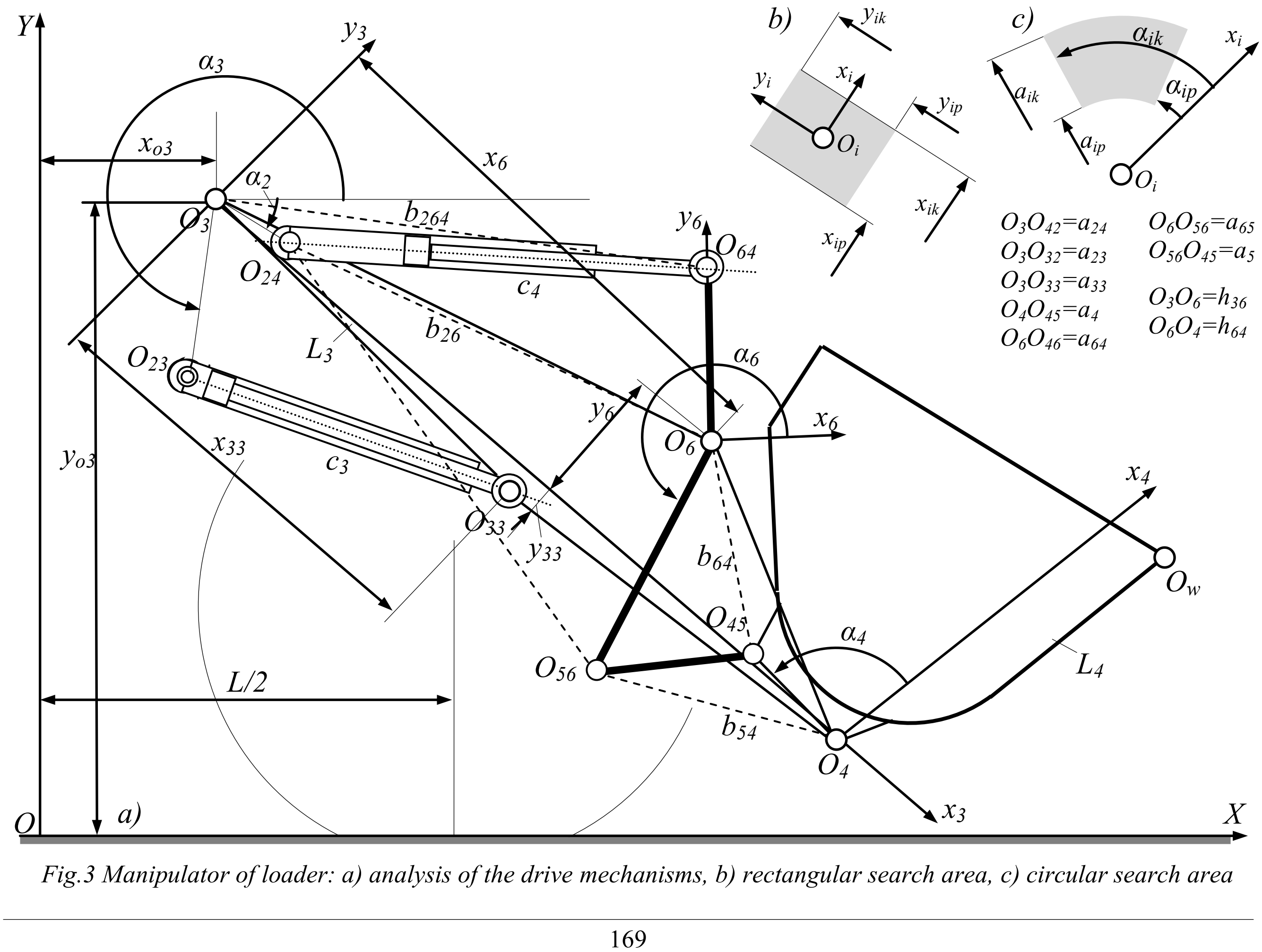

Fig.3 Manipulator of loader: a) analysis of the drive mechanisms, b) rectangular search area, c) circular search area

$$X = (a_{24}, \alpha_2, a_{23}, \alpha_3, x_6, y_6, x_{33}, y_{33}, a_{64}, a_{65}, \alpha_6, a_4, \alpha_4, a_5)^T \quad (15)$$

Two types of search area are defined: when the joint coordinate changes in the local coordinate system of the member along the x and y axes from the initial x_{ip}, y_{ip} to the final boundaries of the search area x_{ik}, y_{ik} (joint coordinates O_6 and O_{33}) (Fig.3 b), and the second type when the length of the lever and the angle of the position of the lever in the local coordinate system change from the initial a_{ip}, α_{ip} to the end values a_{ik}, α_{ik} (joint coordinates O_{23}, O_{24}, O_{64}, O_{56}, O_{45} and the length of the lever a_5) (Fig.3 c) [5][6].
The boundaries of the search area are given in Table 1:

Table 1 Boundaries of the search area

var.	search area	var.	search area
a_{24}	[0,2 m; 0,4 m]	y_{33}	[-0,15 m; 0,15 m]
α_2	[315°; 370°]	a_{64}	[0,62 m; 0,82 m]
a_{23}	[0,3 m; 0,8 m]	a_{65}	[0,65 m; 0,85 m]
α_3	[260°; 280°]	α_6	[10°; 25°]
x_6	[1,6 m; 1,8 m]	a_4	[0,27 m; 0,47 m]
y_6	[0,5 m; 0,7 m]	α_4	[80°; 100°]
x_{33}	[1,3 m; 1,7 m]	a_5	[0,65 m; 0,85 m]

The manipulator drive mechanisms must not have dead positions in the operating range. Dead positions of the mechanisms can occur when the manipulator is at the loading height Y_u and the bucket is maximally rotated by the angle α_u (position I) (Fig. 2) and at the maximum unloading height when the bucket is rotated by the unloading angle α_i (position II) (Fig. 2) [7] [8].
Eliminating dead positions of bucket mechanisms represent a set of optimization constraints in the form of nonlinear inequalities (Fig. 3):

$$g(X) = \{g_i(X)\} \ \forall i = 1,\ldots,7 \quad (16)$$

where:

$$g_1(X) = \left| \frac{a_{65}^2 + a_5^2 - b_{64}^2}{2 \cdot a_{65} \cdot a_5} \right| < 1$$

$$g_2(X) = \left| \frac{a_5^2 + a_4^2 - b_{54}^2}{2 \cdot a_5 \cdot a_4} \right| < 1$$

$$g_3(X) = \left| \frac{b_{64}^2 + a_4^2 - h_{64}^2}{2 \cdot b_{64} \cdot a_4} \right| < 1$$

$$g_4(X) = \left| \frac{a_{24}^2 + c_4^2 - b_{264}^2}{2 \cdot a_{24} \cdot c_4} \right| < 1 \quad (17)$$

$$g_5(X) = \left| \frac{a_{64}^2 + c_4^2 - b_{26}^2}{2 \cdot a_{64} \cdot c_4} \right| < 1$$

$$g_6(X) = \left| \frac{b_{26}^2 + a_{65}^2 - b_{25}^2}{2 \cdot b_{26} \cdot a_{65}} \right| < 1$$

$$g_7(X) = \left| \frac{h_{36}^2 + a_{64}^2 - b_{264}^2}{2 \cdot h_{36} \cdot a_{64}} \right| < 1$$

3. MULTI-CRITERIA OPTIMIZATION BY GENETIC ALGORITHM

The genetic algorithm (GA) was used to solve the problem of search for global extremum.
Genetic algorithm is a method for solving optimization problems with or without constraint based on natural selection. The genetic algorithm repeatedly modifies the population of individual solutions. At each step, the genetic algorithm randomly selects individuals from the current population who will be their parents and uses them to produce children for the next generation. Over the coming generations, the population evolves towards the optimal solution.
A genetic algorithm can be applied to solve various optimization problems that are not suitable for standard optimization algorithms when the goal function is interrupted, non-differential, stochastic, or highly non-linear.
Four features distinguish the genetic algorithm from standard optimization and search procedures:

- Genetic algorithms work with coding a set of parameters, not the parameters themselves.
- Genetic algorithms search with a population of points, not a single point.
- Genetic algorithms use evaluation of objective functions rather than derivates or other ancillary knowledge.
- Genetic algorithms use stochastic rules, not deterministic rules.

These four features contribute to the robustness of the genetic algorithm, whose advantage over standard methods, which have a problem with the local extremum, is characterized by the ability to find a global minimum or maximum.
Multi-objective genetic algorithms are used for Pareto optimum synthesis of manipulator drive mechanisms considering the minimization of three objective functions simultaneously.
The obtained Pareto fronts demonstrate that trade-offs between these three objectives can be recognized so that a designer can optimally compromise for the selection of a desired four-bar linkage.
Objective functions f_1, f_2, f_3 conflict with each other so that improving one of them will deteriorate another one. Consequently, there is no single optimal solution as the best with respect to these three objectives. Instead, there is a set of optimal solutions or Pareto front.
The concept of Pareto front (in the domain of objectives) or set (in the domain of design variables) in multiobjective optimization problems stands for a set of solutions that are non-dominated to each other but are superior to the rest of solutions in the search space. This means that it is not possible to find a single solution to be superior to all other solutions with respect to all objectives so that changing the vector of design variables in such a Pareto set consisting of these non-dominated solutions could not lead to the improvement of all objectives simultaneously. Conseque-ntly, such a change will lead to deteriorating of at least one objective.
Thus, each solution of the Pareto front includes at least one objective inferior to that of another solution in that Pareto

front, although both are superior to others in the rest of search space.

Table 2 shows the non-dominated solutions in the Pareto front obtained by multiobjective genetic algorithm. At the output of the developed program, 70 variant solutions were obtained whose value of the objective functions are given in the form of 2D Pareto front: first f_1 and second f_2 objective functions (Fig. 4a), b) first f_1 and third f_3 objective functions (Fig. 4b) and second f_2 and third f_3 objective functions (Fig. 4c).

Figure 4d gives a 3D view of the Pareto front of all three objective functions together.

The obtained Pareto front gives a clear insight into the optimal solutions that cannot be obtained without the multi-objective Pareto optimization approach.

Which unique optimal solution will be chosen is the process of the decision method, where, by assigning weight coefficients to each objective function, a unique solution will be obtained [9] [10].

Table 2 Non-dominated solutions in Pareto front

P.B.	a_{24}	α_2	a_{23}	α_3	x_6	y_6	x_{33}	y_{33}	a_{64}	a_{65}	α_6	a_4	α_4	a_5
1.	*0,326*	*341,416*	*1,715*	*0,581*	*0,360*	*88,598*	*0,693*	*15,122*	*0,759*	*0,751*	*270,036*	*0,503*	*1,479*	*0,012*
2.	*0,392*	*335,971*	*1,740*	*0,565*	*0,433*	*89,622*	*0,801*	*16,379*	*0,792*	*0,762*	*273,010*	*0,711*	*1,625*	*-0,021*
3.	*0,316*	*335,369*	*1,742*	*0,568*	*0,442*	*89,854*	*0,806*	*16,610*	*0,796*	*0,765*	*274,032*	*0,797*	*1,665*	*-0,133*
4.	*0,333*	*335,628*	*1,749*	*0,555*	*0,462*	*89,836*	*0,811*	*16,471*	*0,794*	*0,766*	*274,035*	*0,794*	*1,659*	*-0,085*
5.	*0,342*	*335,321*	*1,761*	*0,541*	*0,469*	*89,676*	*0,813*	*16,327*	*0,790*	*0,768*	*274,319*	*0,576*	*1,644*	*-0,024*
6.	*0,382*	*336,102*	*1,760*	*0,548*	*0,464*	*89,781*	*0,810*	*16,435*	*0,787*	*0,767*	*273,969*	*0,763*	*1,645*	*-0,034*
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
66.	*0,325*	*348,204*	*1,674*	*0,608*	*0,346*	*87,982*	*0,744*	*15,181*	*0,771*	*0,783*	*271,557*	*0,792*	*1,646*	*-0,029*
67.	*0,393*	*338,302*	*1,734*	*0,572*	*0,413*	*89,555*	*0,792*	*16,144*	*0,783*	*0,764*	*273,341*	*0,661*	*1,620*	*-0,014*
68.	*0,389*	*336,039*	*1,731*	*0,565*	*0,424*	*89,200*	*0,792*	*16,155*	*0,784*	*0,762*	*273,325*	*0,693*	*1,617*	*-0,026*
69.	*0,377*	*335,907*	*1,755*	*0,543*	*0,462*	*89,785*	*0,810*	*16,434*	*0,791*	*0,767*	*273,884*	*0,773*	*1,646*	*-0,058*
70.	*0,300*	*336,125*	*1,761*	*0,548*	*0,469*	*89,849*	*0,810*	*16,130*	*0,789*	*0,766*	*274,366*	*0,790*	*1,622*	*-0,030*

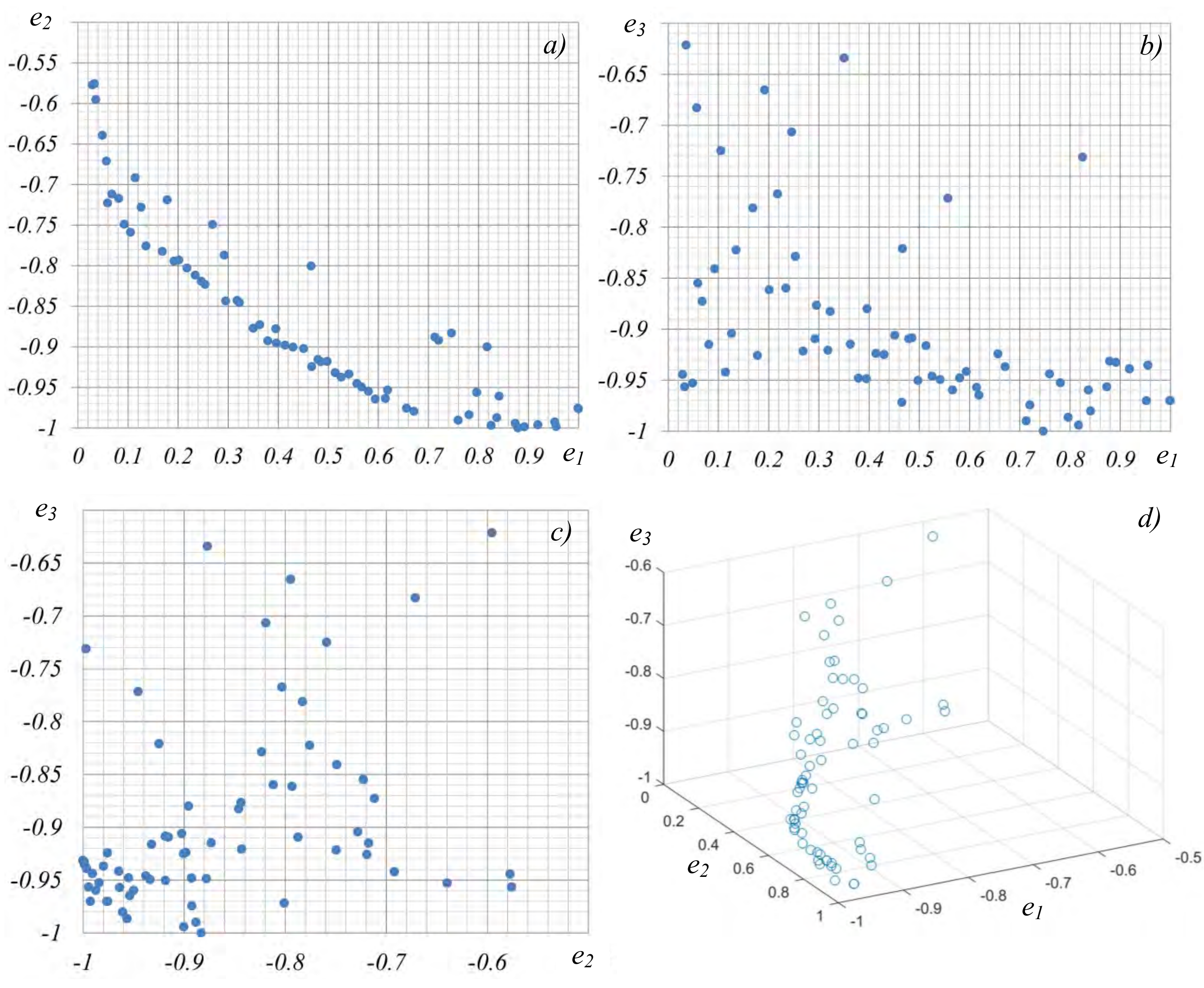

Fig. 4 Pareto front of normalized values of: a) first f_1 and second f_2, b) first f1 and third f_3, c) second f_2 and third f_3 objective functions, d) 3D figure of Pareto front

CONCLUSION

A multi-objective genetic algorithm was used to optimally design drive mechanisms od loader manipulator with Z kinematics. The objective functions which conflict with each other were selected as: minimum change in bucket angle, maximum transfer function of the arm drive mechanism and maximum transfer function of the bucket drive mechanism. It has been shown that optimal solutions could be found among the non-dominated Pareto fronts compromising those conflicting objective functions.
One of the features of the used method is that there is not an unique solution to the problem, as the method finds non-dominated solutions and every non-dominated solution is a good solution to the proposed problem. Hence, the designer must choose which is the best in every case, i.e., he must determine which characteristic or goal function is a priority and which is not.

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Contact address:
Jovan Pavlović
University of Niš
Faculty of Mechanical engineering
18000 Niš
A. Medvedeva 14
E-mail: jovan.pavlović@masfak.ni.ac.rs

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STRUCTURE AND IMPORTANT PARAMETERS CHOICE OF THE TWO-SPEED TWO-CARRIER PLANETARY GEAR TRAINS

Jelena STEFANOVIĆ-MARINOVIĆ [1]
Sanjin TROHA [2]
Miloš MILOVANČEVIĆ [1]
Željko VRCAN [2]

[1] Faculty of Mechanical Engineering, University of Niš, Serbia
[2] Faculty of Engineering, University of Rijeka, Croatia

Abstract

Compared to conventional gear trains, planetary gear trains (PGTs) offer numerous benefits. Multi-stage planetary gear trains are built by linking one or two shafts of two different single-stage planetary gear trains. A special multi-stage PGT type is a two-speed two-carrier PGT consisting of two coupling shafts and four external shafts. There are many important characteristics of this type of compound gear trains, the most notable being the possibility of speed changes under load. The paper presents quickly determination of the structure and important basic parameters of two-speed planetary gear trains that meet predefined transmission requirements. This is enabled by using computer program developed for examination of two-speed planetary gear trains DVOBRZ. The procedure is followed by a numerical example provided to the application at the fishing boat.

Key words*: planetary gear trains, two speed, structure, parameters.*

1 INTRODUCTION

Planetary gear trains (PGT) are a type of gear trains with many advantageous characteristics. Multi-stage planetary gear trains are obtained from single stage gear trains by linking shafts of different planetary stages. Their application as multiple speed gearboxes is especially important. Two speed PGTs are the subject of this paper and we shall consider two-speed two-carrier PGTs with four external shafts composed of two PGTs of the basic type.

Structures of compound gear trains are laid out. The significant number of all possible schemes requires a systematization of the variants, as well as their labelling.
The paper outlines how to quickly determine the structure and important basic parameters of two-speed planetary gear trains that meet predefined transmission requirements. The procedure is followed by a numerical example in which the optimal two-speed planetary gear train is selected, defined by the numbers of teeth of the central gears, modules and transmission ratios. The position of the transmission and working conditions of the both directions of the fishing boat determine the input data for the computer program that define structure and important parameters of the planetary gear train stages.
The basic part of the paper is the review of possible choice of the transmission for any defined application by using a specially developed computer program. The choice between the program obtained variants is then made by comparative analysis of the solutions.

2 TWO-SPEED PLANETARY GEAR TRAINS

By joining two shafts of one component planetary gear train with two shafts of the other component planetary gear train a mechanism with four external shafts is obtained (Fig. 1). Among these four external shafts, two are coupled shafts and two are single external shafts. The component planetary gear trains will be referred to as the component trains and the obtained mechanism with four external shafts will be referred to as the compound train.

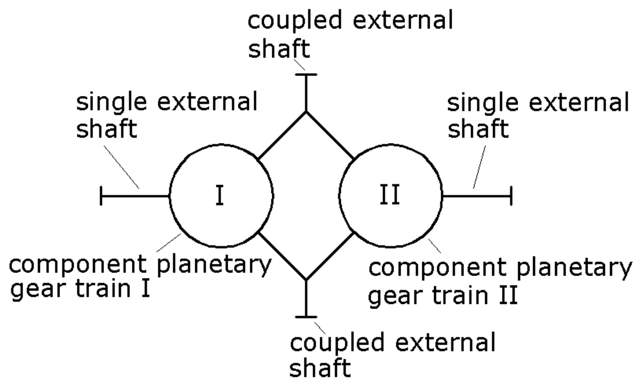


Fig. 1 *Planetary gear train with four external shafts (compound train)*

Both component trains are planetary gear trains of the basic type consisting of sun gear – 1, planet gear (satellite) – 2, ring gear – 3 and carrier – h, as shown in the Fig. 2.
Also, the Wolf-Arnaudov's symbol is presented in Fig. 2. By using this symbol the train shafts are represented by lines of different width and a circle. The sun gear shaft 1 is represented by a thin line, the ring gear shaft 3 by a thick line and the carrier shaft *h* by two parallel lines, since the carrier shaft is the summary element and by locking the carrier a negative transmission ratio is obtained.
Planetary gear train shafts are loaded with torques as indicated in Fig. 2. The torque on the ring gear shaft T_3 and the torque on the carrier shaft T_h are given as functions of the ideal torque ratio t and the torque acting on the sun gear shaft T_1.

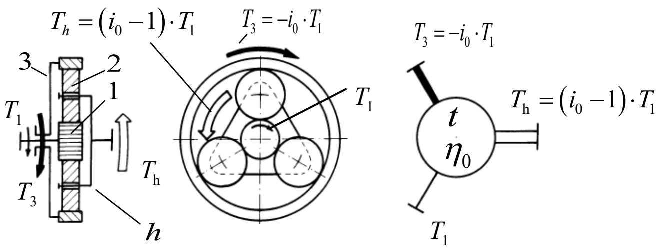


Fig. 2 *Wolf-Arnaudov's symbol and torque ratios of the basic type of PGT [1]*

The ideal torque ratio is

$$t = \frac{T_3}{T_1} = \left|\frac{z_3}{z_1}\right| = -i_0 > +1\,, \qquad (1)$$

where i_0 is the basic transmission ratio, z_1 is the number of teeth of the sun gear and z_3 is the number of teeth of the ring gear.
Two component trains can be joined in a total of 36 possible ways [1,2]. Because of isomorphism, there are only 12 different ways, called planetary gear trains with four external shafts, Fig. 3.

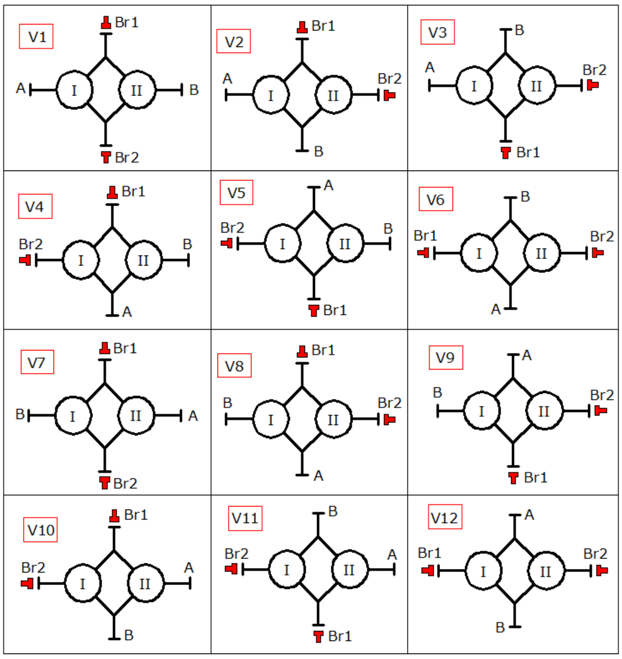


Fig. 4 *Layout variants of two-carrier planetary gear trains with four external shafts [3,4]*

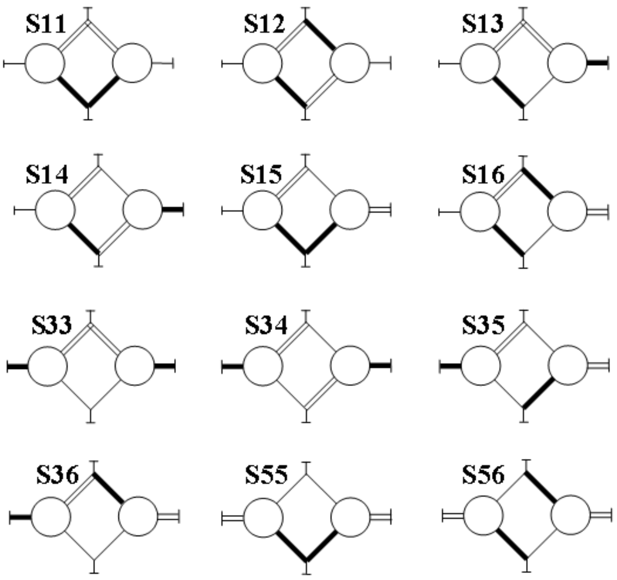


Fig. 3 *Systematization of all schemes of two-carrier planetary gear trains with four external shafts [3]*

In every presented scheme it is possible to put brakes as well as the driving or the operating machine on external shafts in 12 different ways (V1…V12), which are referred to as the layout variants (Fig. 4). By putting brakes on different shafts it is possible to influence the power flow and kinematic characteristics. It is an important advantage, since these transmissions can be used as multiple-speed gearboxes.
By situating the brakes on two shafts a braking system is obtained in which an alternating activation of the brakes shifts the power flow through the planetary gear train, which also causes a change in the transmission ratio. A computer program for the selection of an optimal variant of similar multi-speed planetary gear trains DVOBRZ is described in [2].

3 NUMERICAL EXAMPLE AND DISCUSSION

The application example of two-speed planetary gear trains choice will be shown at the fishing boat transmission. The driving machine is four stroke diesel engine. The input number of revolution is 1800÷2100 min^{-1}. The driving machine works in the heavy duty regime with unlimited working hour during year. Transmission ratio in the regime when transmission works like reducer is in the range i=2.5÷6.
For chosen fishing boat [5] two-speed planetary gear train is applicable as a drive of fishing boats propellers. In that case the transmission works with transmission ratio i=4 in one direction and with transmission ratio i=-4 in the other direction. The transmission is situated on the propeller shaft between engine and propeller.
Based on the requirements and assumptions listed above, the *DVOBRZ* program lists six possible two-speed PGT design structures as acceptable solutions shown in the Table 1 (symbolic view and kinematic scheme) with the main parameters and kinematic capabilities summarized in the Table 2. Taking into consideration that required transmission ratios are i_1=4 and i_2=-4 solutions with transmission ratios are in the ranges i_1=3.85÷4.1 and i_2=(-4.1)÷(-3.85).

The main parameters include the numbers of teeth of all gears and ideal torque ratios in the both stages. The number of satellites is three, except stage with bold numbers of the teeth of satellites where the number of satellites is four. The program DVOBRZ gives the ideal torque ratios for the both stages. On the basis of the ideal torque ratios, the number of teeth of all gears are adopted [6] and presented in the Table 2. The number of teeth are in accordance of the mounting conditions (condition of coaxiallity, condition of adjacency and condition of conjunction). It can be observed that torque ratio t is in some cases less than two, which

indicates satellites are smaller than sun gear and in the first step is necessary to multiplicate the input number of revolution. When the ideal torque ratio is equal three, e.g. transmission ratio is equal four (solution S36V6 and solution S13V3) the number of teeth of the sun gear and number of teeth of the satellites can be different only for one tooth. When torque ratio is greater than three the number of teeth of the sun gear is smaller than number of teeth of satellites and the reduction is in the both steps of planetary gear stage. Only solution S36V6 has the torque ratio greater or close to three in the both stages, while others have smaller torque ratio in one stage.
The optimal solution choice is made by designer according to techno economical demands.

Table 1 Acceptable solutions (A-input shaft; B-output shaft)

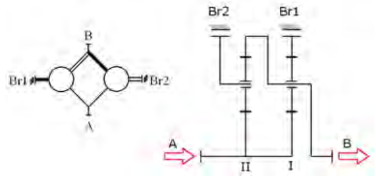
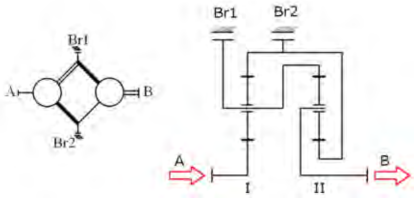
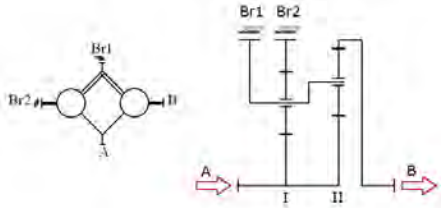
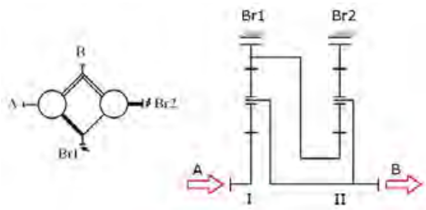
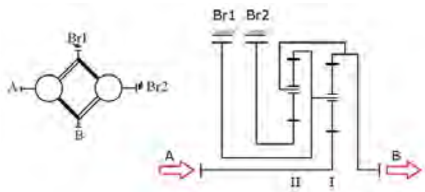
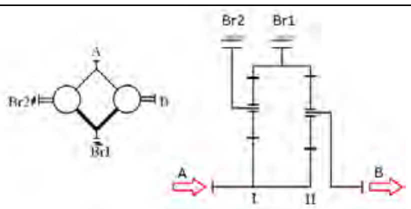
No	Design ation	Kinematic diagram
1	S36V6	
2	S16V1	
3	S33V4	
4	S13V3	
5	S12V2	
6	S55V5	

Table 2 Main parameters of the both stages

Desig nation	t_I	t_{II}	z_{1I}	z_{2I}	z_{3I}	z_{1II}	z_{2II}	z_{3II}
S36V6	2.931	4.053	29	28	85	19	**29**	77
S16V1	1.464	1.651	56	13	82	43	14	71
S33V4	1.464	4.053	56	13	82	19	**29**	77
S13V3	3	1.684	15	**15**	45	38	13	64
S12V2	4.053	1.757	19	**29**	77	37	14	65
S55V5	1.5	3	48	12	72	15	**15**	45

In order to choose the appropriately solution it is necessary to analyse the work regimes of all acceptable solutions.
Detailed description of the first presented variant is given in the [4] and now will be briefly pointed. By activating any brake only one stage works in the active mode, while the other is idling.
At the solution No2, S16V1, in the both regimes regardless to which brake is activated, the both planetary stages work in the two-shaft active mode.
The specificity of the solution S33V4 is in the fact that by activation of brake Br1 only second stage works actively, while by activation of the brake Br2 the both of stages have power circulation.

The fourth solution, marked as S13V3, has similarly characteristic: when brake Br1 is activated the ring gear of the first stage is immovable and only one stage operates in active mode (the first stage), while second stage is idling. When the Br2 is activated the ring gear of the second stage is immovable and the both of stages have power circulation. The same occasion is at the solution S12V2.
The transmission pointed as sixth solution also has power circulation throught both stages when brake Br2 is activated, while by activating brake Br1 only first planetary stage works actively and second planetary stage is idling.
For all acceptable solutions transmission ratios and efficiencies are calculated in the both cases: by activating brake Br1 and brake Br2. Results are presented in the Table 3. Transmission ratio when brake Br1 is activated i_{Br1} and transmission ratio when brake Br2 is activated i_{Br2} are defined by using adopted number of the teeth (Table 3). Also, efficiency when the carrier is immovable-basic efficiency or relative efficiency η_0 [7]. Efficiency when the brake Br1 is activated η_{Br1} and efficiency when the brake Br2 is activated η_{Br2} are calculated as functions of ideal torque ratios and basic efficiencies [2].
The choice of optimal solution in these circumstances is made by analysing data given in the Table 3. First of all, since frequencies of operation at nominal power in the forward directions are greater than frequencies in the reverse mode, greater value for efficiency at brake activation determine usage of brake. That is, for forward direction always chooses work with activation brake which leads to greater efficiency in order to save fuel, since propeller can be dual. Except solution No2, S16V1, all other solutions have greater value of efficiency by activation of the brake Br1.

Since the demand is to select optimal solution according to efficiency, the first solution S36V6 is chosen. Also, this transmission is the appropriate solution according to technological demands, i.e. production.

Table 3 Transmision ratios and efficiencies

mark	i_{Br1}	i_{Br2}	η_{0I}	η_{0II}	η_{Br1}	η_{Br2}
S36V6	3.931	-4.053	0.984681	0.982634	0.988578	0.982634
S16V1	-3.881	3.956	0.972837	0.974329	0.957284	0.974334
S33V4	-4.053	3.857	0.972837	0.982634	0.982634	0.959946
S13V3	4	-4,052	0.971111	0.972255	0.978333	0.930388
S12V2	-4.053	3.876	0.982634	0.974023	0.982634	0.970658
S55V5	4	-4	0.970486	0.971111	0.978333	0.911046

There are no drilled shafts because there are no shafts go through other. This solution is already shown in [4] without the numbers of teeth definition. Since that, the basic efficiency in [4] was not defined, but adopted $\eta_0 = 0.98$. In this paper, the numbers of teeth of all gears of all acceptable solutions are indicated, so basic efficiencies are calculated. Power flow through transmission is presented in the Fig. 5 and in the Fig. 6.

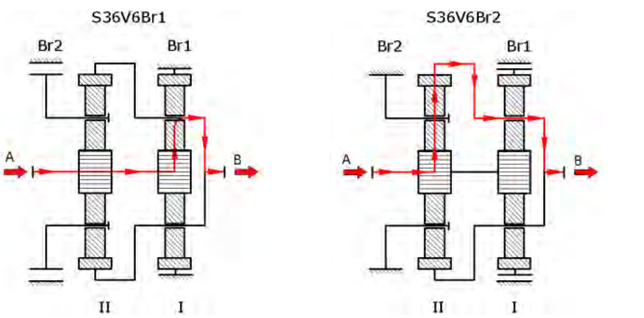


Fig. 5 *Power flow through the transmission when the brake Br1 is activated (a) and when the brake Br2 is activated (b)*

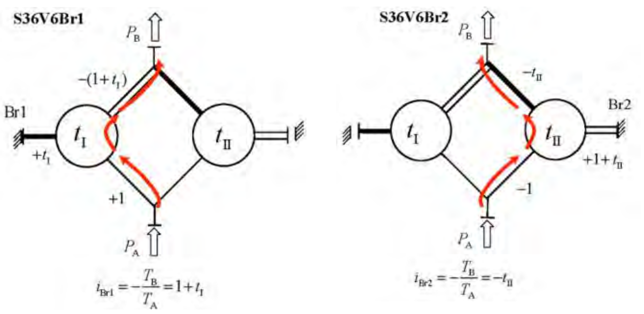


Fig. 6 *Symbolic view with the power flow for solution S36V6: a) Br1 is activated, b) Br2 is activated*

Both brakes are on single external shafts. It is obvious that in both situations, i.e. by activating any brake, only one stage works in the operating mode (two-shaft operating mode), while the other operates idly. Because of that, the power waste occurs in only one PGT stage and there is only one power sink.

CONCLUSION

Two-speed planetary gear trains with four external shafts, composed of two simple planetary gear trains are presented in this paper, including a systematization of their kinematic structures and layout variants. Due to their characteristics, they are applicable in systems which require transmission ratio change under load.
The paper presents quickly determination of the structure and important basic parameters of two-speed planetary gear trains. This is enabled by using computer program developed for examination of two-speed planetary gear trains DVOBRZ. The procedure is followed by a numerical example provided to the application at the fishing boat.
All possible schemes obtained by program are realized and main parameters are defined. The most appropriate scheme is chosen by analyzing obtained schemes according to the efficiency.

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Contact address:
Sanjin Troha
University of Rijeka, Faculty of Engineering
Vukovarska 58, Rijeka, Croatia
E-mail: stroha@riteh.hr

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ANGULAR POSITION MEASUREMENT USING AN ADAPTIVE ABSOLUTE ENCODER

Goran MILJKOVIĆ [1]
Dragan DENIĆ [1]
Milan SIMIĆ [1]
Aleksandar JOCIĆ [1]

[1] *University of Niš, Faculty of Electronic Engineering*

Abstract

Using the pseudorandom encoder to measure the absolute position has proven to be a good solution in practice and can be used in numerous applications. In this paper the adaptive possibilities of pseudorandom encoder are presented, whereby it transforms into a more intelligent measurement transducer. This paper presents the application of several modes of pseudorandom encoder operation with various performances. An encoder solution with the ability of two operating resolutions is presented, depending on the current speed of movement. That is, at a lower speed, higher resolution would be used and vice versa. Also, the encoder can be configured to work as incremental, adaptive, or with only one resolution.

Key words*: position measurement, angular position, pseudorandom absolute encoder*

1 INTRODUCTION

Absolute position encoders provide precise position information used for monitoring or control motion activity. They provide information required for the precise control of a variety of applications, such as positioning a rotary table, pick and place, elevators, packaging, robotics and more. Optical ecoders have a very high reslution/accuracy, best dynamical performance, good resistane to ambiental influences (temperature, shock, vibration). Pseudorandom encoders use a longitudinally arranged binary pseudorandom code, where the read n bits form a code word which has a unique absolute position [1, 2, 3, 4]. To create a new code word, it is enough to read one new bit from the code track. These encoders use a smaller number of code reading heads and have fewer code tracks compared to classical absolute encoders. Also, with the classical absolute encoder, the number of code tracks and the number of code reading heads increases with higher resolution. With pseudorandom absolute encoder, there is no accumulation of errors that occurs in the case of an incremental encoder. Different methods for detecting code reading errors can be applied to pseudorandom absolute encoders in order to increase their reliability [5]. Also, they allow for, using appropriate algorithm [6], easier mounting on the motor shaft and determining the zero position, using serial pseudorandom/natural code conversion method. They can be applied everywhere where a reliable, precise and accurate measurement of the absolute position is required [4, 7].

On the code disk, pseudorandom absolute position encoders usually have one synchronization and pseudorandom code track. A synchronization track is necessary to define the moment of reading the pseudorandom code and to determine the direction of rotation [2, 8]. In this encoder, the read code word must be converted to a natural code, and different types of converters are used [1, 4, 9, 10]. The working angular speed of these encoders, or the time of position determining, depends largely on the encoder resolution, where the pseudorandom / natural code conversion takes most of the time. Typically, but also for easier mounting of the encoder and defining the zero position, a serial pseudorandom/natural converter is applied in pseudorandom encoder which uses a PRBS sequence Fibonacci generator and it needs, depending on the position of the read code word, from 1 to 2n clock periods to complete the conversion process [6, 9, 10].

In the first part of the paper is detailed explained proposed solution of adaptive encoder with adequate order of code track on the encoder disk. The algorithm of the encoder operation and all its possible modes of operation are elaborated in detail. The LabVIEW FPGA implementation was used to demonstrate the functionality and benefits of the proposed absolute encoder.

2 ADAPTIVE RESOLUTION OF POSITION MEASUREMENT

There are numerous applications in the industry with precise position measurements where there are wide changes in angular speed. The pseudorandom absolute position encoder consumes less time to determine the position in the case of using lower resolution. The time of position determination as well as the mechanical constraints defines the maximum angular speed at which the encoder can operate. Two speed limitations can be distinguished to rotary encoders: mechanical and electrical. Mechanical limitation of maximum speed indicates the value which the encoders can withstand without breaking. Electrical speed limit depends on frequency response of the electronics inside the encoder.

The pseudorandom absolute encoder allows us to place two code tracks on the code disk with different resolutions of the pseudorandom binary code. Different combinations of resolutions are possible, which may depend on the particular application. One synchronization track would be used to define the timing of code reading for both code tracks. Also, the synchronization track would be used to determine the direction of rotation as well as to measure the angular speed.

The pseudorandom encoder presented in the paper is the one which has one synchronization track and two code tracks of different resolutions on the code disk. Two reading heads are required for the synchronization track and one for reading each of the two pseudorandom code tracks. Depending on the angular speed, the encoder can determine the position using a single code track, at higher speeds with a lower resolution and vice versa. The proposal for layout of the code tracks on the encoder disk is shown in Figure 1, where the resolutions n = 8 (PRBS code: 0000000101110001110111100010 1100110110000111100111000010101111111100101111010 0101000011011101101111101011101000001100101010100 0110101100011000001001011011010100110100111111011 1001100111101100100001000000111001001001100010011 10101011010001000101001000111111) for the first code track and n = 4 (PRBS code: 000100110101111) for the second code track were taken [11], mostly due to the size and clarity of the image in order to explain the proposed solution. With three tracks from the code disk, four signals are obtained using four reading heads as in Figure 2.

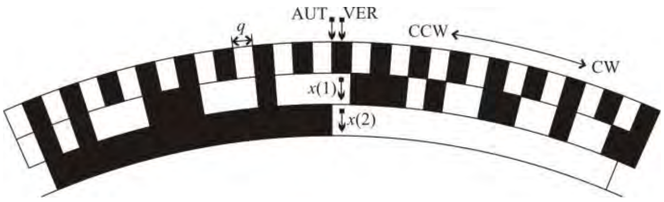

Fig. 1 *Part of the pseudorandom encoder code disk.*

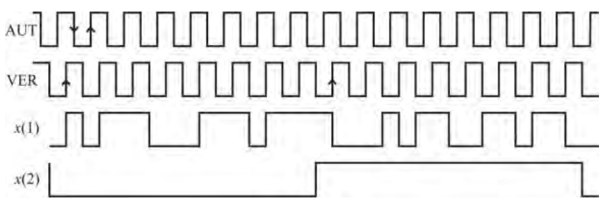

Fig. 2 *Signals from the encoder disk in the case of CCW direction of rotation.*

The presented pseudorandom absolute encoder would have four operating modes that can be manually selected on the encoder enclosure or from the control centre, Figure 3. The signals from the AUT and VER reading heads are used at all times to determine the direction of rotation and angular speed. The angular speed can be calculated by the M method, which is more accurate at higher speeds or CET method, which has good accuracy over a wider range of speeds [12]. Also, the rising and falling edges from these signals are used to synchronize the reading of the pseudorandom code.

If the encoder operates as a pseudorandom absolute encoder with n=8 bit resolution, the synchronization and first code track is used, or if it works with n=4 bit resolution, the synchronization and second code track is used. From Figure 2, it can be seen that in the case of reading a code track with a lower resolution, each eighth rising edge of the VER signal is used. If you choose to use the encoder in incremental mode, only the synchronization track would be used.

An adaptive mode of operation is proposed here where the encoder at a higher angular speed would operate at a lower resolution n = 4, and at lower speeds with a higher resolution n = 8, which would have better stability of the encoder operation in a wider range of angular speeds.

3 LabVIEW FPGA implementation

In order to explain the advantages of this encoder, suppose the encoder electronics is realized by a FPGA circuit that operates at a clock speed of 40 MHz (T = 25 ns), as in National Instruments PCIe-7841R acquisition card. During the position measurement, we will use the conversion time of serial pseudorandom/natural code converter that mostly determines the total measurement time; other contributions in the measurement time can be neglected.

The serial pseudorandom/natural code conversion was used to easily adjust the zero position for both code tracks. In the LabVIEW FPGA software, serial code converters for resolutions of n = 6 to n = 12 were made and conversion times were measured for the worst case, when the code converter needed the maximum number of steps to complete the conversion. Figure 4 shows the appearance of the serial code converter in the LabVIEW FPGA for resolution n = 6, whereby it was measured on FPGA target PCIe-7841R that 601 ticks were needed to complete the worst case conversion of the code word 010000, if the initial code word is 1000000.

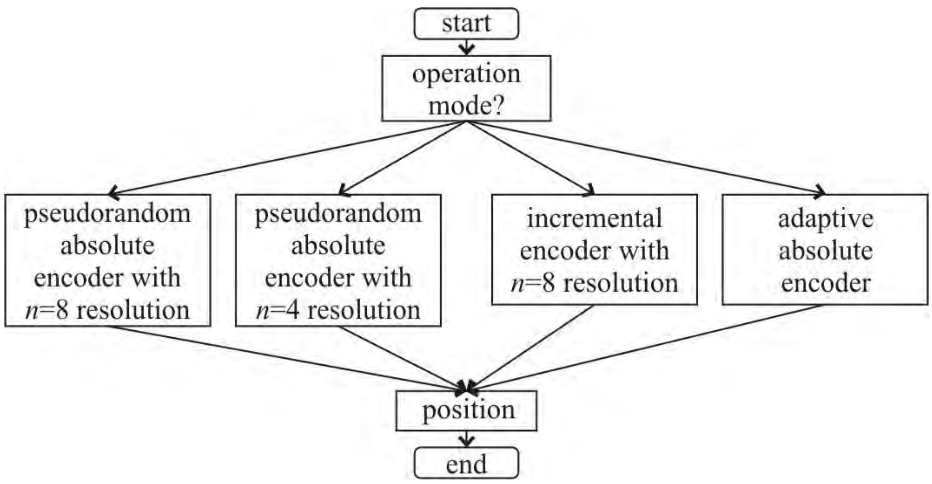

Fig. 3 *Operation algorithm of pseudorandom absolute encoder.*

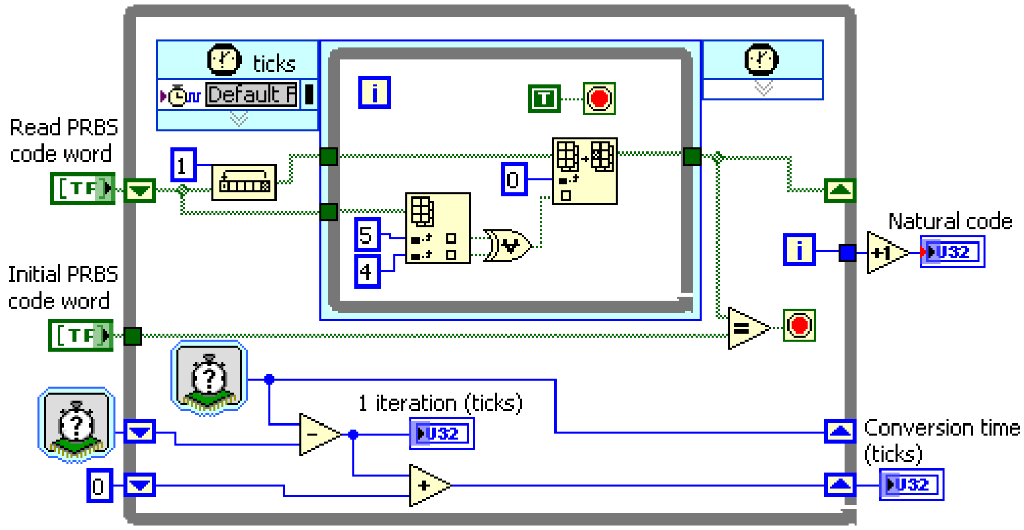

Fig. 4 *Serial pseudorandom/natural code converter for resolution n=6 in LabVIEW FPGA.*

The serial code converter can be further optimized using VHDL programming. The measured conversion times are used to calculate the maximum angular speed at which the encoder can operate. Figure 5 shows the dependence of the angular speed at which the encoder can rotate and the encoder resolutions, where it can be observed that the measurement time significantly limits the encoder angular speed as we move to higher resolutions, greater than 8 bits.

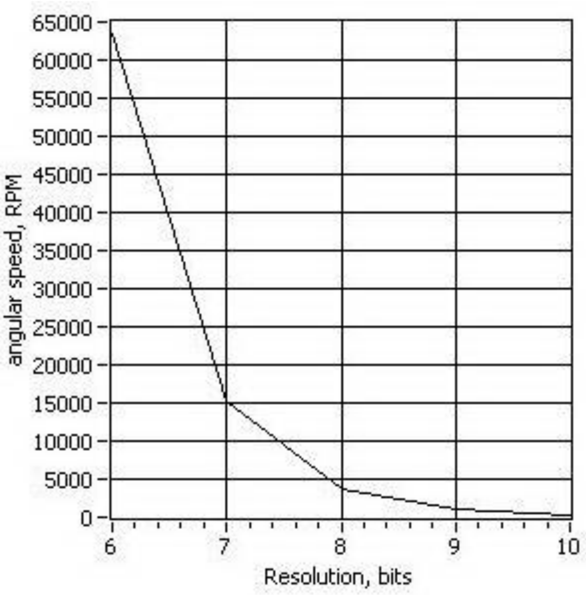

Fig. 5 *Dependence of angular speed on encoder resolution.*

Based on the measurement time of the position, it is necessary to determine the angular speed at which the encoder will work steadily with high resolution, while at speeds greater than that, it would work with a lower resolution. In order to do this, the encoder determines the position at the same time with both a higher and a lower resolution using one of these two values depending on the angular speed. This principle of operation of an encoder can also be applied to linear position measurement, for example for positioning in different transport systems, cranes control, automated guided vehicles, etc. Apart from the introduced adaptability properties, depending on the angular speed, the encoder can add various methods for checking the code reading errors in order to increase its reliability, as well as the operation of the encoder in the event when some of the code tracks are dirty or failure of some code reading head.

4 CONCLUSION

A pseudorandom absolute encoder with multiple modes of operation is presented and now, as an intelligent measuring transducer, can be adapted to the specific needs of the concrete application. The encoder constructed in this way can reliably work in a wider range of angular speeds. For different specific applications, the most optimal code track resolutions on the encoder disk can be defined.

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Contact address:
Goran Miljković
Elektronski fakultet u Nišu
18000 NIŠ
A. Medvedeva 14
E-mail: goran.miljkovic@elfak.ni.ac.rs

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LEAVING THE LINE PATH

Predrag RAJKOVIĆ [1]
Ljiljana RADOVIĆ [1]

[1)] Department for Mathematics, Faculty of Mechanical Engineering, University of Niš, Serbia

Abstract

When people are told of someone as being "off the right track", they think they have done something wrong and the question is whether they can be corrected. In doing so, there is no objective assessment of how far it is from the right path and whether it returns to it in the next steps.
This problem is very similar to moving along some trajectory. The linearity of a curve can be understood as the integral transformation that associates an ordered pair of functions with the linearity function of the curve they define. The whole theory can be extended to the other shapes and multidimensional problems.This procedure is also interesting from the point of view of comparing curves that can be used to determine the class to which a curve belongs, to analyze signatures, to check a batch of products, etc.

Key words: *path, linearity, integral transformation, measure, signature.*

1 INTRODUCTION

The useful informations can be extracted from images just by examining the edges of the objects. Measuring their linearity can be used for identifying them and differing from the others (see [1]-[4]). For example, it can be used in recognizing a road by a photo of its part or a car in a column. An object becomes more easily recognizable if it is dissected into an ordered collection of curves. The linearity of a finite set of points can be used for identifying the components of a picture.

We can find the second application in the linear theory of hydrologic systems what can be find in [5] and seen on the Fig 1. The whole hydrologic cycle is a closed system in the sense that the water circulating always remains within the system. Here, we can notice some lines of water transport which express: precipitation, evaporation, transpiration, and run off.

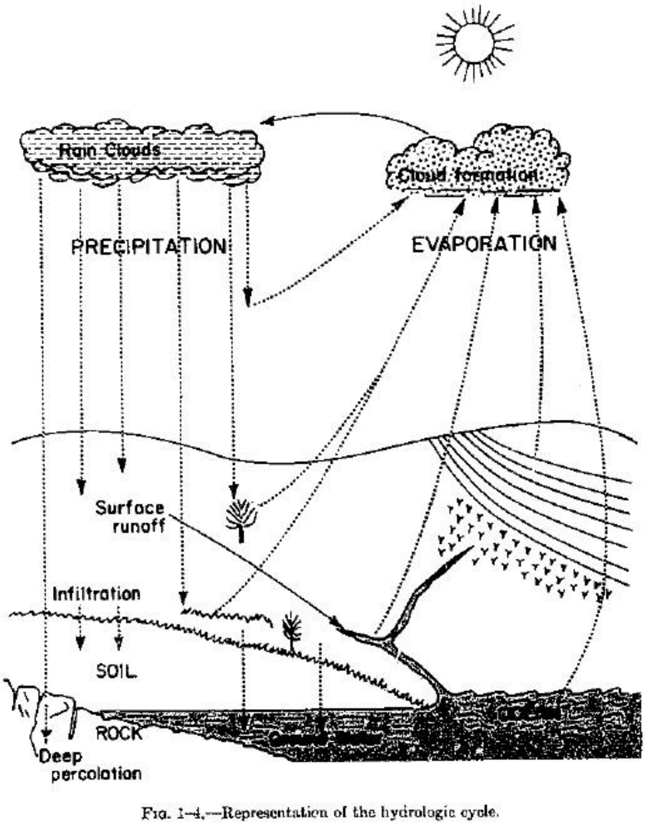

Fig. 1 *The lines of water transport in a hydrologic system*

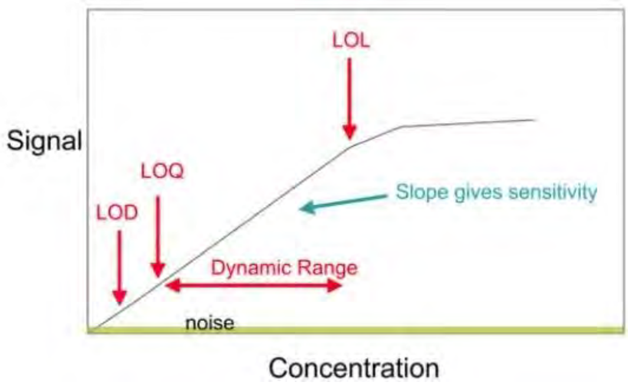

Fig. 2 *The calibration curve*

The third application can be found in the chemistry [6]. Namely, a large number of analytical methods require the calibration of an instrument. Instrument calibration is a set of operations that establish the relationship between the output of the measurement system and the accepted values of the calibration standards.
The linear range of most analytical instruments is known to be limited. Therefore, during method validation the linearity of the calibration curve should be assessed and the working range of the calibration curve should be determined.On the Fig.2 can be seen a calibration curve plot showing limit of detection (LOD), limit of quantification (LOQ), dynamic range, and limit of linearity (LOL).

2 ARC LENGTH PARAMETRIZATION

Any curve in Oxy plane can be represented by a map

$$\alpha(t) = (x(t), y(t)): \quad (a,b) \to R^2 \tag{1}$$

We say that a curve is smooth if $x(t)$ and $y(t)$ are continuous functions with continuos derivatives. In that case, its velocity and speed at time can be defined by

$$\alpha'(t) = (x'(t), y'(t)),$$
$$|\alpha'(t)| = \sqrt{(x'(t))^2 + (y'(t))^2}. \tag{2}$$

A curve is regular if it is a smooth curve such that

$$|\alpha'(t)| \neq 0, \quad \forall t \in (a,b). \tag{3}$$

That is, a regular curve is a smooth curve with everywhere nonzero velocity. Its length is defined by

$$\text{Length}(\alpha(t); a, b) = \int_a^b \sqrt{(x'(t))^2 + (y'(t))^2}\, dt. \tag{4}$$

Every regular curve can be representated in a lot of parametrizations such that the path holds on and speed change. Namely, let

$$h(u): \quad (c,d) \to (a,b) \tag{5}$$

be a diffeomorphism, i.e., $h(u)$ and $h^{-1}(u)$ are bijective and smooth functions. Then

$$\overline{\alpha}(u) = \alpha(h(u)): \quad (c,d) \to R^2 \tag{6}$$

is a *reparametrization* of the curve α.
The reparametrization is the orientation preserving if $h'(u) > 0, \forall u \in (c,d)$. For opposite sign, it is orientation reversing reparameterization.
Regular curves can be always parameterized in terms of arc length.
We say that a curve is given in the arc length parmatrization If

$$\overline{\alpha}(s) = (\overline{x}(s), \overline{y}(s)): \quad (0, S) \to R^2, \tag{7}$$

and

$$\text{Length}(\overline{\alpha}(u); 0, s) = s, \quad \forall s > 0. \tag{8}$$

The connection between any variable and arc length variable can be found by

$$s = \int_a^t \sqrt{(x'(u))^2 + (y'(u))^2}\, du. \tag{9}$$

Example 1 The representation of a line segment

$$x = at, \quad y = bt, \quad t \in (0,c) \tag{10}$$

is not the arc length representation because of

$$\sqrt{(x'(t))^2 + (y'(t))^2} = \sqrt{a^2 + b^2}. \tag{11}$$

But, it can be easily written in the wanted form

$$x = \frac{as}{\sqrt{a^2+b^2}}, \quad y = \frac{bs}{\sqrt{a^2+b^2}},$$
$$s \in (0, c\sqrt{a^2+b^2}). \tag{12}$$

Example 2 The representation of a circular arc

$$x = \cos s, \quad y = \sin s, \quad s \in (0,b) \tag{13}$$

is the arc-length representation because of

$$|\alpha'(s)| = \sqrt{(x'(s))^2 + (y'(s))^2} = 1, \forall s \in (0,b). \tag{14}$$

Example 3 The representation of a plane spiral shown on Fig 3.,

$$x = e^{at}\cos bt, \quad y = e^{at}\sin bt, \quad t \in (0,c) \tag{15}$$

is not the arc length representation because of

$$|\alpha'(t)| = e^{at}\sqrt{a^2+b^2}. \tag{16}$$

Hence

$$s = \frac{1}{a}\sqrt{a^2+b^2}\left(e^{at}-1\right), \tag{17}$$

wherefrom

$$t = \frac{1}{a}\ln\left(1 + \frac{as}{\sqrt{a^2+b^2}}\right). \tag{18}$$

Finally, arc-length representation is

$$x = \left(1 + \frac{as}{\sqrt{a^2+b^2}}\right)\cos\left(\frac{b}{a}\ln\left(1 + \frac{as}{\sqrt{a^2+b^2}}\right)\right),$$
$$y = \left(1 + \frac{as}{\sqrt{a^2+b^2}}\right)\sin\left(\frac{b}{a}\ln\left(1 + \frac{as}{\sqrt{a^2+b^2}}\right)\right),$$
$$s \in \left(0, \frac{1}{a}\sqrt{a^2+b^2}\left(e^{ac}-1\right)\right). \tag{19}$$

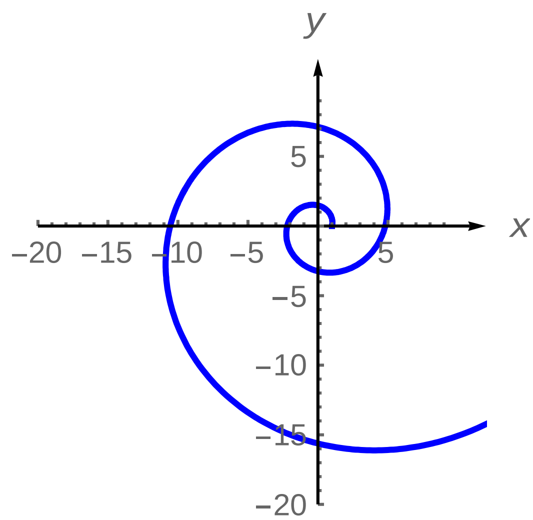

Fig. 3 *The spiral for a=1 and b=2.*

Similarly, we can consider the three-dimensional curve

$$\alpha(t) = \left(x(t), y(t), z(t)\right): \quad (a,b) \to R^3 \tag{20}$$

Its length is

$$\text{Length}(\alpha(t);a,b) = \int_a^b \sqrt{\left(x'(t)\right)^2 + \left(y'(t)\right)^2 + \left(z'(t)\right)^2}\, dt. \tag{21}$$

Example 4 The representation of the helix

$$x = a\cos t, \quad y = a\sin t, \quad z = bt, \quad t \in (0,h), \tag{22}$$

can be transformed into the arc length representation by

$$x = a\cos\frac{s}{c}, y = a\sin\frac{s}{c}, z = \frac{bs}{c}, \ s \in (0,ch), \tag{23}$$

where $c = \sqrt{a^2 + b^2}$.

But, there are many cases when the integral in (9), may not be computed exactly. Then, we have to approximate curve by multiline or to apply numerical integration.

3 MEASURE OF LINEARITY OF A CURVE

If a curve is given in the arc-length parametrization, then the its length form the point $M_0 = (x(s_0), y(s_0))$ to the point $M = (x(s), y(s))$ is less than $|s - s_0|$, i.e.,

$$\left(x(s) - x(s_0)\right)^2 + \left(y(s) - y(s_0)\right)^2 \le \left(s - s_0\right)^2. \tag{24}$$

The equality is fulfilled if and only the curve is a straight line. It is consequence of the fact that the shortest distance between two points is over the line. It can be proven by a graphics of any curve.
The relation (17) was defined and examined in the papers [1]-[4]. Hence the definition of the linearity of a curve was derived.
We will suggest more abstract approach. Let us define the *linearity measure* as the integral transform

$$Lm\left(\{x(s), y(s)\}\,; z\right) = \frac{6}{z^4}\int_0^z\int_0^z \left(\left(x(s) - x(s_0)\right)^2 + \left(y(s) - y(s_0)\right)^2\right) \mathrm{d}s\mathrm{d}s_0. \tag{25}$$

If we introduce

$$M_{pq}(z) = \int_0^z\int_0^z \left(x(s)\right)^p \left(y(s)\right)^q \ \mathrm{d}s\mathrm{d}s_0, \tag{26}$$

we can write

$$Lm\left(\{x(s), y(s)\}\,; z\right) = \frac{12}{z^4}\left(zM_{20}(z) + zM_{02}(z) - M_{10}^2(z) - M_{01}^2(z)\right). \tag{27}$$

Theorem 1 The linearity measure (28) is bounded

$$0 \le Lm\left(\{x(s), y(s)\}\,; z\right) \le 1. \tag{28}$$

Especially, it is identically equal to 1 if and only if the curve is the straight line.
Proof. Notice that

$$\int_0^z \left(s - s_0\right)^2 \ \mathrm{d}s_0 = \frac{z^3}{3} - sz^2 + s^2 z, \tag{29}$$

wherefrom

$$\frac{6}{z^4}\int_0^z\int_0^z \left(s - s_0\right)^2 \ \mathrm{d}s\mathrm{d}s_0 = 1. \tag{30}$$

Since the integrand is nonnegative and using (27), we finish the proof. □

Example 5 The linearity measure of the circular arc is

$$Lm\left(\{\cos s, \sin s\}\,; z\right) = \frac{12}{z^4}\left(z^2 + 2\cos z - 2\right). \tag{31}$$

Notice that

$$\lim_{z\to\infty} Lm\left(\{\cos s, \sin s\}\,; z\right) = 0. \tag{32}$$

It means that the linearity value becomes zero when we enter into a circle and continue to move on it.

Theorem 2 The linearity measure is invariant under translation and rotation of a curve, i.e., if

$$\begin{gathered} X(s) = a + x(s)\cos\alpha + y(s)\sin\alpha, \\ Y(s) = b - x(s)\sin\alpha + y(s)\cos\alpha, \\ (a, b, \alpha \in R), \end{gathered} \tag{33}$$

then

$$Lm\left(\{X(s), Y(s)\}\,; z\right) = Lm\left(\{x(s), y(s)\}\,; z\right). \tag{34}$$

The linearity measure (18) is oriented from the beginning to the end of curve.

Theorem 3 Let $\alpha(s) = \left(x(s), y(s)\right): \quad (0,S) \to R^2$ be arc length parametrization of a curve. The linearity measure of reverse oriented curve is

$$Lm\left(\{x_{\text{rev}}(s), y_{\text{rev}}(s)\}; z\right) = Lm\left(\{x(1-s), x(1-s)\}; z\right). \tag{35}$$

Example 6 Let us consider multiline (see Fig. 4) through three points

$$A(0,0), B(2/3,0)C(2/3,1/3).$$

On thee Fig. 5, the measure of linearity of oriented multiline ABC is shown by red color thick curve and by blue dashed curve is shown measure of linearity of CBA.

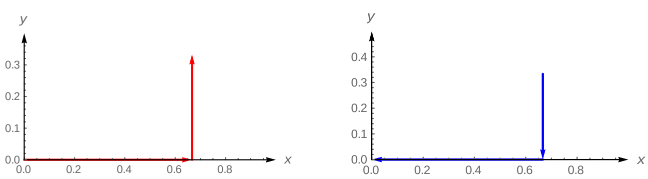

***Fig. 4** Oriented and reverse oriented multiline*

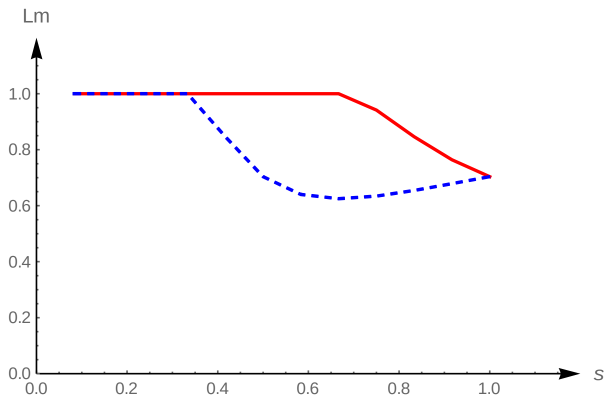

Fig. 5 *The measure of linearity: red for the oriented and blue for reverse oriented multline*

Example 7 The linearity measure of a random multiline on Fig. 6 is shown on Fig 7.

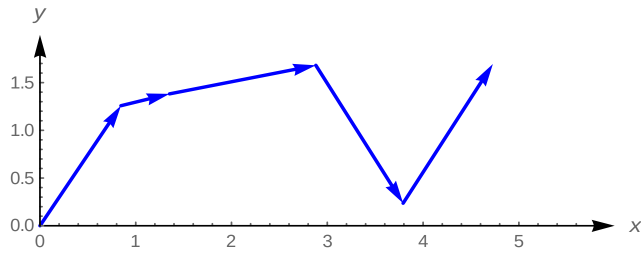

Fig. 6 *An orineted random multiline*

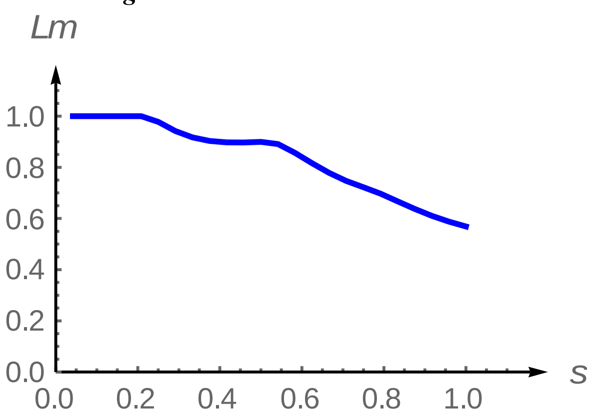

Fig. 7 *Measure of linearity of the line shown on Fig. 4*

The *linearity measure* of a three-dimensional curve can be defined as the integral transform

$$Lm(\{x(s),y(s),z(s)\};z)=\frac{6}{z^4}\int_0^z\int_0^z\begin{pmatrix}(x(s)-x(s_0))^2+\\(y(s)-y(s_0))^2\\+(z(s)-z(s_0))^2\end{pmatrix}\mathrm{d}s\mathrm{d}s_0. \tag{36}$$

Example 8 The linearity measure of the helix Fig 8., is

$$Lm\left(\{\cos\frac{s}{\sqrt{2}},\sin\frac{s}{\sqrt{2}},\frac{s}{\sqrt{2}}\}\mid z\right)=\frac{1}{2}+\frac{12}{z^4}\left(z^2+4\cos\frac{z}{\sqrt{2}}-4\right). \tag{37}$$

Notice that

$$\lim_{z\to\infty}Lm\left(\{\cos\frac{s}{\sqrt{2}},\sin\frac{s}{\sqrt{2}},\frac{s}{\sqrt{2}}\}\mid z\right)=\frac{1}{2}.$$

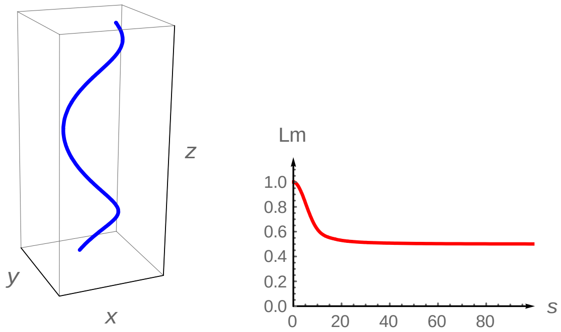

Fig. 8 *Helix and its linearity measure*

4 NUMERICAL APPROACH

There are many cases when we are not able to find arc-length parametrization exactly. It is often the consequence of the fact that we can not compute the integral. So, we must apply the numerical integration.
Even we did the previous computation exactly, the computation of measure of linearity itsself includes the integral with variable upper bound. So, we have to apply the numerical integral computation again. Here, we can use the Newton-Cotes or Gaussian quadratures applied in the software Wolfram Mathematica [7].

5 LINEARITY NEARNESS OF THE CURVES

The previous considerations can be used to compare the linearity measure of two curves (see [3]). Namely, we are able compute the area bounded by the graphs of their linearity measures

$$Area(Lm(C_1),Lm(C_2))=\int_0^v|Lm(C_1;z)-Lm(C_2;z)|dz. \tag{38}$$

Also, it is useful to include these curves in reverse direction. Now, the distance beetwen their linearity measures can be defined by

$$L_d(C_1,C_2)=\min\left\{\begin{matrix}Area(Lm(C_1),Lm(C_2)),\\Area(Lm(C_{1,\mathrm{rev}}),Lm(C_{2,\mathrm{rev}}))\end{matrix}\right\}. \tag{39}$$

If it is a small positive number, we can say that the curves are near in the sense of their linearity.

Example 9 Let us consider the red multiline through the points $A(0,0),B(1,1)C(2,1)D(2,2),$ and the second one which is derived by random small moves of the previos vertices (see Fig. 9).

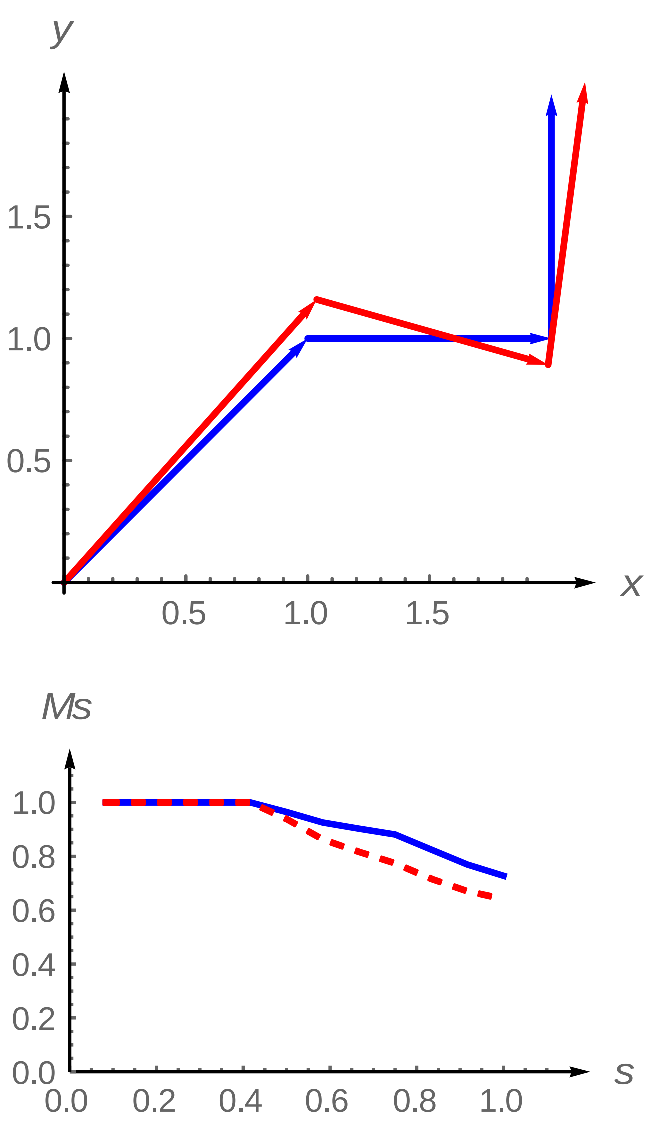

Fig. 9 *Two close multilines and their linearity measures*

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Contact address:
Predrag Rajković
University of Niš
Faculty of Mechanical engineering
18000 Niš
A. Medvedeva 14
E-mail: pedja.rajk@masfak.ni.ac.rs

UNIVERSITY OF NIS
FACULTY OF MECHANICAL ENGINEERING
Department of Transport Engineering and Logistics

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