TEHNIČKI GLASNIK

TEHNIČKI GLASNIK / TECHNICAL JOURNAL – GODIŠTE / VOLUME 15 – BROJ / ISSUE 4

PROSINAC 2021 / DECEMBER 2021 – STRANICA / PAGES 449-584

/

SVEUČILIŠTE SJEVER / UNIVERSITY NORTH – CROATIA – EUROPE

ISSN 1846-6168 (PRINT) / ISSN 1848-5588 (ONLINE)

TECHNICAL JOURNAL

ISSN 1846-6168 (Print) ISSN 1848-5588 (Online)

TEHNIČKI GLASNIK - TECHNICAL JOURNAL

Scientific-professional journal of University North

Volume 15 Issue 4
Varaždin, December 2021 Pages 449–584

Editorial Office:
Sveučilište Sjever / University North – Tehnički glasnik / Technical journal
Sveučilišni centar Varaždin / University Center Varaždin
Jurja Križanića 31b, 42000 Varaždin, Croatia
Tel. ++385 42 493 338, Fax.++385 42 493 336
E-mail: tehnickiglasnik@unin.hr
https://tehnickiglasnik.unin.hr
https://www.unin.hr/djelatnost/izdavastvo/tehnicki-glasnik/
https://hrcak.srce.hr/tehnickiglasnik

Founder and Publisher:
Sveučilište Sjever / University North

Print:
Centar za digitalno nakladništvo, Sveučilište Sjever

All manuscripts published in journal have been reviewed.
Manuscripts are not returned.

The journal is free of charge and four issues per year are published
(In March, June, September and December)
Circulation: 100 copies

Journal is indexed and abstracted in:
Web of Science Core Collection (Emerging Sources Citation Index - ESCI), EBSCOhost Academic Search Complete, EBSCOhost – One Belt, One Road Reference Source Product, ERIH PLUS, CITEFACTOR – Academic Scientific Journals, DOAJ – Directory of Open Access Journals, Hrčak – Portal znanstvenih časopisa RH

Registration of journal:
The journal "Tehnički glasnik" is listed in the HGK Register on the issuance and distribution of printed editions on the 18th October 2007 under number 825.

Preparation ended:	**Published:**
October 31, 2021	November 1, 2021

Legend:
(1) University North, (2) University of Slavonski Brod, (3) Faculty of Graphic Arts Zagreb, (4) Faculty of Civil Engineering Osijek, (5) Faculty of Engineering Rijeka, (6) Faculty of Mechanical Engineering and Naval Architecture Zagreb, (7) Faculty of Metallurgy Sisak, (8) Tomas Bata University in Zlín, (9) Department of Physics of the University of Josip Juraj Strossmayer in Osijek, (10) Faculty of Humanities and Social Sciences Osijek, (11) Karlovac University of Applied Sciences, (12) University of Applied Sciences Velika Gorica, (13) Department of Polytechnics - Faculty of Humanities and Social Sciences Rijeka, (14) Faculty of Electrical Engineering and Computer Science - University of Maribor, (15) Faculty of Civil Engineering - University of Maribor, (16) University College of Teacher Education of Christian Churches Vienna/Krems, (17) Faculty of Mechanical Engineering - Poznan University of Technology (Poland), (18) Mechanical Engineering Faculty Sarajevo, (19) University of Travnik - Faculty of Technical Studies, (20) Higher Education Technical School of Professional Studies in Novi Sad, (21) University of Novi Sad - Faculty of Technical Sciences, (22) Faculty of Mechanical Engineering - University of Montenegro, (23) Brno University of Technology, (24) Odessa State Academy of Civil Engineering and Architecture, (25) Faculty of Civil Engineering - University of Mostar, (26) Faculty of Manufacturing Technologies with the seat in Prešov - Technical University in Košice, (27) Faculty of Mechanical Engineering - University of Maribor, (28) College of Engineering, IT & Environment - Charles Darwin University, (29) Universite Libre de Bruxelles, (30) Vishwakarma Institute of Information Technology (Pune, India), (31) AISSMS Institute of Information Technology (Pune, India), (32) Permtech Research Solutions (India), (33) University of Belgrade, (34) National Dong Hwa University - Taiwan, (35) Faculty of Mechanical Engineering - Opole University of Technology (Poland)

ISSN 1846-6168 (Print), ISSN 1848-5588 (Online)
https://doi.org/10.31803/tg-20200919194215

Original scientific paper

Investigating and Prioritizing Factors Affecting Technology Selection Using Multi Criteria Decision Making Methods in the National Iranian Petrochemical Company

Seyed Hossein Nouri, Tahmoures Sohrabi*

Abstract: Technology can be considered as the most important factor in changing human experiences. Much of the success of most top companies in the field of competition rests on innovative activities that often rely on technology. On the other hand, defining valid and reliable as well as measurable indicators is necessary in order to make the most accurate decision. This refers to the famous saying that anything that can be measured can be managed. Therefore, using various scientific sources, the present study seeks to identify indicators of appropriate technology selection and then, prioritize them using multi-criteria decision making methods in the National Iranian Petrochemical Company. For this purpose, first important factors have been identified by studying the research literature and utilizing experts' opinion gathered and aggregated by Delphi method. Then, by these factors have been ranked by screening and final identification through a hybrid approach of TOPSIS and Shannon entropy. According to the obtained results, technology efficiency has the highest priority among the factors which shows that in technology with the highest level of efficiency must be transferred and used in petrochemical industry. The competitive effects of technology have the lowest priority which shows that it is the least impact for technology transfer in this industry, and it need less attention from the industry practitioners.

Keywords: MADM; Petrochemical Industry; Shannon Entropy; Technology Selection; TOPSIS Method

1 INTRODUCTION

As the most important factor in changing human experiences [1], technology refers to the knowledge, skills, techniques and tools needed to convert resources into products [2]. The performance of each company is affected by six important economic factors Including capital, manpower, management, products, resources and technology. In today's markets with increasing changes, the ability of organizations to use new technologies is a sustainable competitive advantage [3]. The major part of the success of most successful companies relies on innovative activities that are often based on technology [4]. On the other hand, more accurate decision-making requires the definition of indicators with a high level of validity and reliability, as well as the possibility of measuring them. Because it is well known in management that anything that can be measured can be managed. Accordingly, utilizing various scientific literature, the present study seeks to develop indicators to select the appropriate technology and then prioritize them using multi-criteria decision making methods.

1.1 Research Problem Statement and Literature Review

Today, due to the issue of rising costs, the complexity technological change, and global competition and technology resources, the strategic importance of technology has received much attention [1, 5]. Hence, playing a vital role in business, technology causes creating and maintaining the core competencies of an organization for better performance than competitors and business success [6]. Organizations must be able to select the right technologies to be competitive and adapt to emerging technologies.

Lack of accurate and scientific identification and selection of technologies is one of the main problems of organizations. It is mostly due to their emphasis on key indicators such as cost or revenue, which are not the only factors to achieve organizational success and development. One of the main and key elements of technology strategy is the selection of technologies for development. The technology selection for development refers to identify those technologies that need to be upgraded, or in other words, not suitable for the organization and there is a gap between the current and the desired situation regarding them. Due to the importance of this issue, the present study aimed to identify and prioritize technology selection indicators in the Iranian National Petrochemical Company. The research literature and background are presented in the following section.

A strategic technology planning model have been developed by Reshnavadi and Rouhollahi (2018) in Iranian petrochemical industry using network analysis process that macro goals and strategies are significantly related to industry technology strategies and alternatives and the contribution of each in achieving the ultimate goals is determined by sensitivity analysis. The vision of change and its effects on criteria and alternatives have been created to deal with change, scenarios and have been used for decision making. The process of producing olefins and paraffin, polymer, Nano composites, polymer membranes and membrane and hybrid bioreactors, polyethylene terephthalate, methanol synthesis catalyst and acetic acid synthesis catalyst have been selected as the technology priorities of the petrochemical industry [7].

The criteria of technology suppliers' selection have been identified and prioritized in the study conducted by Eskandari et al. (2017) in industry in the Arak Petrochemical Company. In this paper, PESTLE / SWOT analysis is used to identify internal and external factors affecting the technology supplier selection system. These factors are classified into six categories of political, economic, social, technical, legal, and environmental, and then divided according to their positive or negative effect on the system. Finally, these factors are provided for ranking using the fuzzy VIKOR method. These

factors are then used for the purpose of technology suppliers' selection in Arak Petrochemical Company [8].

Green technology evaluation and selection in Iran's cement industry to reduce environmental pollutants using MCDM techniques have been addressed in Mousavi et al. (2017). Selecting green technology in the policies of countries is an effective factor in combating climate change. The purpose of this study is to evaluate and select green technology in the cement industry. According to the obtained results, lattice preheaters, furnaces with calcination apparatus and rotary cooling were selected as green technological options.

In a research to identify and prioritize the factors affecting the Technology Transfer Selection Methods, Haseli et al. (2017) used the fuzzy BWM method to study the food and beverage industry. This research has identified and prioritized the factors affecting the technology transfer methods of the industry using fuzzy BWM method in order to manage and improve the technology transfer process in the food industry [9].

Using fuzzy MADM techniques, Sadeghian and Karari (2016) have identified and prioritized the technology selection strategies. In their research, first, the concepts of strategy and technology strategy are reviewed and then, while using the SWOT method in identifying and selecting technology strategy and using multi-criteria MADM fuzzy decision-making techniques, simple fuzzy cumulative weighting in a car parts company, priorities has been given to the identified strategies and the most appropriate technology strategy has been selected [10].

After reviewing the research theoretical foundations and background, the technology selection indicators are provided in Tab. 1.

Table 1 Technology selection indicators

Row	Researcher	Dimension	Indicator
1	Drejer (1996) [11]	Justification of productive cells	Impact on customer satisfaction, improvement during production and launching cycle, speed of responding to changing market demands and also improving the operation process
2	Chan et al. (2000) [10]	Advanced technology selection	Cost, performance, quality, delivery, flexibility, innovation
3	Hax et al. (1996) [13]	New technology selection	Effectiveness, applicability, implementation duration, cost and risk
4	Sadeghi et al. (2019) [12]	ERP selection process	Adaptability, flexibility, process improvement, customer satisfaction and implementation time
5	Yu-Lung (2010) [14]	Evaluating the performance of the production system	Dependence, flexibility, time, quality and cost
6	Saen (2006) [15]	Deciding on flexible production systems	Quality, cost, productivity, customer satisfaction, dependence, adaptability, competitiveness and top management commitment
7	Jordan et al. (2003) [16]	Software evaluation (CMMS)	Cost, performance, implementation, reliability, efficiency and reparability
8	Khalil (2000) [17]	Investigating the challenges of advancing the operationalization of the technology selection framework	Reliability, quality, cost of capital,
9	Liwarcin et al. (2006) [18]	Selecting new technology	Flexibility, compatibility, cost, vendor, strategy alignment
10	Machado et al. (1997) [19]	Evaluation and selection of ERP systems	Performance, strategic alignment, flexibility, user-friendliness, implementation time, total cost and reliability
11	Torkkeli (2002) [20]	Selection of lean manufacturing systems	Financial factors, organizational factors, top management role, impact on employees, impact on suppliers, impact on customers, impact on shareholders and projected benefits
12	Torkkeli (2002) [20]	Selection of lean manufacturing systems	Technology and strategic fit
13	Markus et al. (2017) [21]	Selecting new technology	Productivity, quality, cost, delivery, flexibility, innovation and employee morale
14	Mitchell et al. (1985) [22]	Selection of advanced production technology	Investment cost, latency, capacity, space required, process flexibility, product quality, training, and employee disturbance
15	Mohrman, et al. (1990) [23]	Selection of advanced production technology	Cost, flexibility, reliability, quality, efficiency and the impact of new technology on employees
16	Khouja (2005) [24]	Evaluation of advanced production technology for world class	Cost, flexibility, efficiency, quality, reliability and impact on human resources
17	Hax et al. (1996), Torkkeli (2002), Shehabuddeen et al. (2006) [3, 11, 25]	Capabilities	Technological capabilities and research and development background
18	Ford (1998), Pegel (1996) [11, 26]	Competition	Competitive effects of technology
19	Prahalad et al. (1990), Watts et al. (1997), Radosevic (1999) [27-29]	Sanctions	Political, legal and executive factors of economic sanctions

2 RESEARCH METHOD

The present study is an applied research in terms of the purpose because its results can be used by organizations and human societies and a descriptive research in terms of nature because the researcher does not manipulate the results

obtained from the data. The tool used in this research is a researcher-made questionnaire. Thus, technology selection indicators in Iran's petrochemical industry after identification have been provided to research experts to agree on the most effective indicators. After the reviews, the list of agreed indicators is as follows [30, 31]: A five-point Likert scale is also used to answer the questionnaire questions. Shannon and TOPSIS entropy [32] combinations were used to data analysis.

Table 2 Technology selection indicators

No. of expert	Experience	Education
1	40	Bachelor degree
2	36	MSc.
3	38	MSc.
4	44	Bachelor degree
5	41	Bachelor degree
6	39	MSc.
7	35	MSc.
8	37	MSc.

The research statistical population is consisted of managers specializing in Iran's petrochemical industry for technology transfer. The profile of these people is as it is given in Tab. 2. Variables related to the National Iranian Petrochemical Company are selected based on the Delphi method. As mentioned before, a questionnaire is designed and distributed among 8 experts. Experts comment on the Likert scale from 1 (least important) to 5 (most important).If the average opinion of experts is 4 or less, that variable is rejected and if it is 4 or higher, that variable is accepted.

3 DATA ANALYSIS

Twenty factors have been considered for this research based on the Delphi method (Tab. 3), of which 5 variables have been rejected and 15 variables have been accepted.

Table 3 Delphi method results

Row	Indicators by importance	Mean	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Expert 6	Expert 7	Expert 8	Accept/reject
1	Productivity	4.375	4	5	5	4	3	4	5	5	Accept
2	Technology complexity and technology dependence	4.5	5	4	3	5	4	5	5	5	Accept
3	Price	4.25	5	4	3	4	4	5	5	4	Accept
4	Knowledge transfer between internal and external organizational units	3.875	3	4	3	5	3	4	4	5	Reject
5	Need for new standard	3.875	3	4	3	4	4	3	5	5	Reject
6	Maintenance and repair costs	4.25	5	4	3	5	5	4	4	4	Accept
7	Flexibility in the face of market changes and customer needs	4.25	3	3	4	4	5	5	5	5	Accept
8	Market changes and customer needs	4.375	4	5	5	5	5	4	4	3	Accept
9	Simple operation and training of forces	4.375	5	4	5	5	5	4	3	4	Accept
10	Environmental compatibility and the amount of pollution produced	3.5	4	3	4	3	3	3	3	5	Reject
11	Implementation time	4.5	5	4	3	5	5	4	5	5	Accept
12	Availability of cheap material and the amount of material consumed	4.375	5	4	3	4	4	5	5	5	Accept
13	Safety in operation	4.375	3	5	4	4	5	4	5	5	Accept
14	Safety when leaving the service	4.375	5	5	4	3	4	4	5	5	Accept
15	Safety during Shutdown	4.375	5	4	3	5	5	5	4	4	Accept
16	Productivity and usefulness according to price	4.625	5	4	5	5	4	5	4	5	Accept
17	Availability of executive contractors	4.5	5	4	3	5	4	5	5	5	Accept
18	Availability of parts and manufacturers	4.5	3	5	4	5	4	5	5	5	Accept
19	Competitive effects of technology	3.625	4	3	5	4	4	3	3	3	Reject
20	Possibility of technology localization	3.875	5	3	3	4	5	4	3	4	Reject

Table 4 Expert weighting by Shannon entropy method

Person	Expert1	Expert 2	Expert 3	Expert 4	Expert 5	Expert 6	Expert 7	Expert 8
P1	6	6	8	4	6	8	5	8
P2	7	6	8	5	7	8	6	8
P3	8	6	8	5	7	8	5	8
P4	6	7	8	5	8	8	5	9
P5	7	8	9	6	8	9	6	9
P6	8	7	6	6	9	5	7	5
P7	9	4	7	7	9	6	7	6
P8	9	5	5	8	5	5	8	7
P9	4	6	6	8	6	4	9	8
P10	5	7	7	9	7	5	8	9
Weight	0.08	0.12	0.1	0.09	0.18	0.08	0.09	0.16
K	0.434294							

Due to the different opinions of each respondent according to their expertise and background, the weight of each opinion is different, so, the Shannon entropy method is used to obtain these weights.

In this step, we will rank the variables affecting technology transfer based on the TOPSIS method. In the first step, the decision matrix is formed. In this matrix, experts give each of the variables a number from 1 to 9 equivalent to the least to the most important.

In the second step, the matrix is normalized. This normalization is performed based on the type of index.

The decision matrix is actually parametric and needs to be quantified, and for this purpose, the decision maker determines the weight for each index. The set of weights is multiplied by the normalized matrix.

Table 5 Initial decision matrix

Matrix	Criterion 11	Criterion 12	Criterion 13	Criterion 14	Criterion 15	Criterion 16	Criterion 17	Criterion 18
Production productivity	6	8	6	7	8	9	7	8
Technology complexity and technology dependence	6	8	7	9	9	8	7	5
Price	9	8	7	7	9	8	9	8
Maintenance and repair costs	9	8	7	8	7	8	7	6
Flexibility in the face of market changes and customer needs	9	8	6	7	7	8	9	8
Simple operation and training of specialized personnel	7	5	8	6	7	9	8	9
Environmental compatibility and the amount of pollution produced	6	9	8	7	6	7	8	9
Availability of cheap material and the amount of material consumed	7	8	9	8	6	7	7	6
Safety in operation	7	6	9	8	7	9	8	9
Safety when leaving the service	8	7	6	8	7	8	9	9
Safety during Shutdown	8	7	6	8	9	8	9	7
Productivity and usefulness according to price	9	7	9	8	7	5	7	6
Availability of executive contractors	9	8	7	5	6	9	8	7
Availability of parts and manufacturers	8	9	8	6	8	7	6	5
Technology competitive effects	8	7	8	9	7	8	9	8
Criteria type	P	P	P	P	P	P	P	P
Criteria weight	0.084569	0.122841	0.195835	0.089413	0.176618	0.079223	0.091795	0.159704
Production productivity	6	8	6	7	8	9	7	8
Technology complexity and technology dependence	6	8	7	9	9	8	7	5

Table 6 The best worst solution

Optimal solution	Criterion 11	Criterion 12	Criterion 13	Criterion 14	Criterion 15	Criterion 16	Criterion 17	Criterion 18
+	0.025	0.0375	0.060	0.027	0.055	0.023	0.026	0.049
-	0.016	0.0209	0.040	0.014	0.037	0.012	0.017	0.027

The two virtual options created are actually the worst and best solutions. The distance between each alternative is measured by the Euclidean method. That is, the distance between the alternatives and the positive and negative ideal alternatives is calculated.

In the Tab. 7, the variables are ranked based on the proximity coefficient.

Table 7 The results ranking

Result	Proximity coefficient
Production productivity	0.6631
Technology complexity and technology dependence	0.6458
Price	0.6279
Maintenance and repair costs	0.5844
Flexibility in the face of market changes and customer needs	0.5457
Simple operation and training of specialized personnel	0.5326
Environmental compatibility and the amount of pollution produced	0.5289
Availability of cheap material and the amount of material consumed	0.5173
Safety in operation	0.5123
Safety when leaving the service	0.5113
Safety during Shutdown	0.4985
Productivity and usefulness according to price	0.4943
Availability of executive contractors	0.4842
Availability of parts and manufacturers	0.4608
Technology competitive effects	0.4465

4 CONCLUSION

As one of the most important industries, the chemical industry has been of special interest to countries in the past few decades, and this has led to its prosperity and pervasiveness in the world. It is currently the third largest industry in the world after the food and automotive industries. The variety of products and the supply of raw materials for thousands of downstream workshops and factories by it, has caused this industry to play a very effective role in the country's economy in terms of job creation, earning foreign exchange earnings and cutting dependence.

The country’s petrochemical industry mechanism should be such that it faces the least challenge in financing its projects and developing this industry. Perhaps one of the most fundamental challenges facing Iran's petrochemical industry is this factor. For this purpose, first the important factors for this matter were identified based on research literature as well as interviews with experts. Then it is tried to coordinate these factors with this industry in Iran. Therefore, the Delphi method was used in which, 8 experts were asked to comment on these factors. At the beginning of the study, 20 factors were counted and based on the Delphi method, 5 factors were eliminated and 15 factors were confirmed. After screening and final identification of indicators, these factors were ranked. Since in this research, weight is considered for each expert based on specialization, degree and work experience, etc., Shannon entropy method has been used to meet this requirement.

The TOPSIS method is then used to rank these factors. According to the obtained results, the technology productivity factor has the highest priority. This means that technology with the highest level of efficiency must be transferred and used in the petrochemical industry.

The competitive effects of technology have the lowest priority and show that in this industry, the competitive effects of technology have the least impact for technology transfer, and petrochemical companies should pay less attention to this factor. Since the research experts were the managers of this company, it was difficult to access them. As a hybrid method of Shannon and TOPSIS has been used in this research, two separate questionnaires had to be prepared and presented to the experts. Also, the number of tables in the TOPSIS method for completion by experts has been high due to the large number of criteria and sub-criteria, which has led to a decrease in the reliability of expert responses and prolongation of the research process.

The following items can be considered in future research: the model presented in this study that is implemented in the National Iranian Petrochemical Company, can be used in other industries, especially related industries such as oil, gas and refining industries, etc. This model can also be combined with other MADM methods such as WASPAS, ELECTER, MULTIMOORA, and so on.

5 REFERENCES

[1] APCTT. (1998). *Atlas Technology: A Framework for Technology Planning*. APCTT Publications.

[2] Arasti, M. R. & Verent M. (1997). A Hierarchical Approach to Evaluation & Selection of Strategic Technology. *Proceeding of the 2nd International Conference on Advances*, 425-431.

[3] Broun, E. (1998). Technology in Context: Technology Assessment for Managers. Routledge, 70-76.

[4] Burgelman, R A., Maidique, M. A., and Wheelwright, S. C. (1995). *Managing Technology and Innovation in Established Firms*. Richard D. Irwin, Chicago, IL. Second Edition, 45-57.

[5] Chapelet, B. & Tovstiga, G. (1998). Development of a Research Mythology for Assessing a Firm's Business process -Related Technologies. *Journal of Technology Management, 15*(1-2), 110-118. https://doi.org/10.1504/IJTM.1998.002596

[6] Chiesa, V. (2001). R&D strategy and organization. *Series on Technology Management, Vol. 5*, p. 292. https://doi.org/10.1142/p223

[7] Clarke, K., et al. (1995). Technology Strategy in UK firms. *Technology Analysis & Strategic Management, 7*(2), 169-190. https://doi.org/10.1080/09537329508524203

[8] Danila, N. (1989). Strategic Evaluation and Selection of R&D Project. *R&D management, 19*(1), 47-62. https://doi.org/10.1111/j.1467-9310.1989.tb00615.x

[9] Drejer, A. (1996). Frameworks for the Management of Technology: Towards a Contingent Approach. *Technology Analysis & Strategic Management, 8*(1), 9-20. https://doi.org/10.1080/09537329608524229

[10] Chan, F. T. S., Chan, M. H., & Tang, N. K. H. (2000). Evaluation methodologies for technology selection. *Journal of Materials Processing Technology, 107*, 330-337. https://doi.org/10.1016/S0924-0136(00)00679-8

[11] Ford, D. (1998). Develop Your Technology Strategy. *Long-Range Planning, 21*(5), 85-94. https://doi.org/10.1016/0024-6301(88)90109-4

[12] Sadeghi, A., Azar, A., Valmohammadi, C., & Alirezaei, A. (2019). Designing a product-service supply chain performance evaluation model in the home appliance industry using factor analysis and fuzzy neural networks Case study: home appliance companies in Iran. *Journal of Production and Operations Management, 10*(2), 83-123. https://doi.org/10.22108/jpom.2019.116300.1193.

[13] Hax, A. C. & Majluf, N. S. (1996). *The Strategy Concept & Process: A Pragmatic Approach*. Prentice Hall

[14] Hsu, Y.-L., Lee, C.-H., & Kreng, V. B. (2010). The application of Fuzzy Delphi Method and Fuzzy AHP in lubricant regenerative technology selection. *Expert Systems with Applications, 37*, 419-425. https://doi.org/10.1016/j.eswa.2009.05.068

[15] Saen, R. F. (2006). A decision model for technology selection in the existence of both cardinal and ordinal data. *Applied Mathematics and Computation, 181*, 1600-1608. https://doi.org/10.1016/j.amc.2006.03.012

[16] Jordan, J., Watkins, A., Fleming, G. South, B., Schwartz, R., Oglesby, D., Ingram, J., & Tominack, B. (2003). Development of Rapid Technology Assessment Tools-A New Paradigm in Aerodynamic Design. *Proceedings of the 49th International Instrumentation Symposium*.

[17] Khalil, T. M. (2000). *Management of Technology: The Key to Competitiveness and Wealth Creation*. McGraw Hill.

[18] Liwarcin, O. & Soyak, B. (2006). A new approach for the diagnosis of strategic problems in technology management. *PICMET, Portland International Conference on Management of Engineering and Technology*, Istanbul, Turkey, July, 8-13. https://doi.org/10.1109/PICMET.2006.296552

[19] Machado, F. M. (1997). Technology Management for Leap-Frogging Industrial Development: The Challenge for Developing Countries at the Beginning of the New Millennium. UNIDO, Vienna

[20] Torkkeli, M. & Tuominen, M. (2002). The contribution of technology selection to core competencies. *Int. J. Production Economics, 77*, 271-284. https://doi.org/10.1016/S0925-5273(01)00227-4

[21] Markus, L. & Jacob, S. (2017). Strategic technology adoption and hedging under incomplete markets. *Journal of Banking & Finance, 81*, 181-199. https://doi.org/10.1016/j.jbankfin.2016.09.008

[22] Mitchell, G. R. (1985). A New Approach for the Strategic Management of Technology. *Technology in Society, 7*, 227-239. https://doi.org/10.1016/0160-791X(85)90027-2

[23] Von Glinow, M. A. & Mohrman, S. A. (Eds.) (1990). Beyond the Clash: Managing High Technology Professionals. In *Managing Complexity in High Technology Organizations*. Oxford University press, 3-14.

[24] Khouja, M. (2005). Joint inventory and technology selection decisions. *Omega, 33*(1), 47-53. https://doi.org/10.1016/j.omega.2004.03.006

[25] Shehabuddeen, N., Probert, D., & Phaal, R. (2006). From theory to practice: challenges in operationalising a technology selection framework. *Technovation, 26*, 324-335. https://doi.org/10.1016/j.technovation.2004.10.017

[26] Pegels, C. C. & Thirumurthy, M. V. (1996). The Impact of Technology Strategy on Firm Performance. IEEE Transaction on Engineering Management, 43(3), 246-249. https://doi.org/10.1109/17.511835

[27] Prahalad, C. K. & Hamel, G. (1990). The Core Competence of the Corporation. Harvard Business Review, May-June, 79-91.

[28] Watts, R. J. & Porter, A. L. (1997). Innovation Forecasting. *Technological Forecasting and Social Change, 56*, 25-47. https://doi.org/10.1016/S0040-1625(97)00050-4

[29] Radosevic, S. (1999). International Technology Transfer and Catch-up in Economic Development. Edward Elgar Pub.

[30] Sharif, N. (1986). Technology Policy Formulation and Planning. Bangalore, India: APCTT.

[31] Stieglitz, J. E. (1998). More instruments and broader goals: moving toward the Post-Washing consensus. WIDER Annual

Lectures 2, World Institute for Development Economics Research, The United Nations University, Helsinki, Finland.
[32] UNIDO. (2019). Technology Needs Assessment (TNA) for Developing Countries.

Authors' contacts:

Seyed Hossein Nouri, M.Sc. Student
Faculty of Management, Islamic Azad University,
Central Tehran Branch, Azadi Str., 123456 Tehran, Iran

Dr. **Tahmoures Sohrabi,** Assistant Professor
(Corresponding Author)
Faculty of Management, Islamic Azad University,
Central Tehran Branch, Azadi Str., 123456 Tehran, Iran
dr.tahmoures.sohrabi@gmail.com

ISSN 1846-6168 (Print), ISSN 1848-5588 (Online)
https://doi.org/10.31803/tg-20210108180723

Original scientific paper

Spatial Data Infrastructure in Natural Disaster Management

Slobodanka Ključanin*, Milan Rezo, Suada Džebo, Emina Hadžić

Abstract: Natural disasters that cause tremendous material harm and threaten human lives, infrastructure, and economic and social activities become more frequent. While most material and human casualties are the effects of sudden and brief natural disasters, it is not possible to disregard long-term disasters, most frequently triggered by climate change. Damage from long-term disasters is quite significant and hampers the sustainability of the economy and life in densely populated cities. Following climate change, it is concluded that special attention should be paid to coastal cities, cities along rivers and the potential risks of possible disasters should be reduced before they materialize. The reduction of disaster risk is an endeavor involving various professional fields, viewpoints, and stakeholders. An integrated approach that brings together all the necessary elements is therefore required. The planning for protection against natural disasters and in the very moments when it occurs, it is necessary to quickly obtain reliable data to coordinate activities in the field well. However, there are problems in the field with the availability, access, and spatial data use. In this sense, the Spatial Data Infrastructure (SDI) can provide an appropriate framework for sharing spatial data through the cooperation of administration, public, and private institutions and citizens.

Keywords: natural disasters; spatial data; spatial data infrastructure

1 INTRODUCTION

The term natural disasters require a precise definition, as there are some terminologies associated with this term. In large part of the professional literature, one can find claims that natural disasters do not exist. Only natural hazards can turn into disasters due to the significant exposure of people, animals, and material goods. However, the fact that we deal only with those dangers that turn into a catastrophe allows us to deal with them to reduce them and prevent them, to reduce the risks. In this context, the hazard is a phenomenon that can damage property and other public resources and interrupt economic and social operations and cause injury or loss of human life and deterioration of the environment ([1, 2]). A natural hazard is the result of earthquakes, landslides, volcanic eruptions, floods, or storms in the form of geophysical, geological, or hydrometeorological activity [3]. A natural hazard can escalate into a natural disaster (see Fig. 1). A natural disaster results from exposure to risky elements and the community's inability to cope with the situation ([4, 2]).

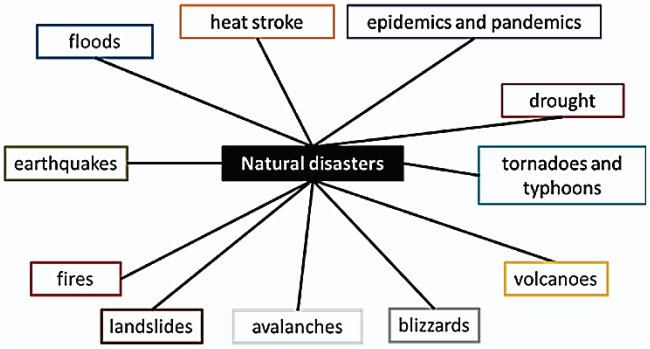


Figure 1 Examples of natural disasters

The degree of risk of disasters in a particular place is a function of hazard, vulnerability, and resilience. Vulnerability is a state of possible danger-related harm or damage. Resilience is a condition in which, by using its own tools to recover its pre-examined circumstances and functions, a structure or society undergoing a catastrophe can survive its impacts. However, it is not straightforward to measure resistance; other approaches should therefore be used in economic or systemic terms to calculate risk [5]. In the Methodology for assessing Bosnia and Herzegovina's threat from natural or other disasters [6], the terminology used for vulnerability, its assessment, exposure to gambling, and the risk of the natural disaster. Vulnerability refers to specific physical, social, and economic factors or environmental processes that raise a community's vulnerability to a particular hazard. Vulnerability assessment is a continuous assessment of the presence and impact of risk elements on people's safety, their property (including domestic animals), and the environment. Gambling exposure means the number, types, quality, and monetary value of various types of material goods or infrastructure and life that may be subject to undesirable hazards that may cause physical injury. Exposure is the only quantification of the risk in the identified hazard zone. The hazard of a natural catastrophe is the likelihood of adverse effects or anticipated damages (dead, destroyed buildings, families, interruption of economic development, or environmental destruction) resulting from encounters between hazards triggered by natural or human activities and circumstances of vulnerability.

In battling the challenge of climate change, optimum resource allocation is very important. In this way, a greater understanding of risk makes for a proactive rather than a reactive strategy. As an important part of asset management, which is included in ISO 55001: 2014, risk recognition and management were recognized. For risk identification and prevention, the main steps are:

- Hazard identification,
- Risk analysis, and
- Risk evaluation [7].

Geospatial data can be beneficial and significant in decision-making at all stages of risk management. Initially,

geospatial data were mostly used to respond to a disaster adequately, but later their role extended to the entire risk management decision-making cycle. Avoiding major disasters begins with identifying hazards in a particular area. In addition, an assessment of the vulnerability of people, facilities, and property should be made. Disaster risk management begins with creating a database of geospatial data, inventory, overlapping layers, risk analysis, costs, scenarios, probabilities, sensitivities, decision matrices, spatial statistics correlations, and many other spatial analyzes and algorithms. After defining the most vulnerable areas, the mitigation process begins. The next step is to prepare a scenario in case of natural hazard. Geospatial databases can help identify shelters, alternative evacuation routes outside the danger zone, hospital capacity, etc. It is also possible to estimate the amount of food, water, and medicine for a particular area. With geospatial data, analyzes are performed during a disaster to perform damage assessment very quickly. Other activities where GIS is beneficial in the event of a disaster are: determining the area for evacuation, delivery of various aids, identification of damaged or blocked roads, planning routes for emergency supplies, identification of locations, people, equipment, shelters, and other resources needed for disaster management. The post-disaster phase includes recovery and reconstruction. It is a process of restoring vital qualities and rebuilding the entire community. Disaster management includes a set of activities that start with the mitigation consequences of the disaster, organizing emergency activities (search and rescue the living things, firefighting) and help in recovery from natural disasters. Recovery from natural disasters includes the physical reconstruction of facilities and the restoration of quality of life after a disaster. Quality spatial information is a fundamental condition for efficient disaster management. However, current studies show significant problems with managing spatial information (i.e., data) needed for disaster management concerning data collection, sharing, access, and use [8].

There are problems with spatial data management that become even more serious in the disaster response phase. Action during natural disasters is dynamic, and decision-makers must have the latest spatial data to react adequately and quickly. Any delay in the collection, access, use, and exchange of data is detrimental to the quality of decision-making and the quality of disaster response. With this in mind, appropriate frameworks and technologies should be used to address the spatial data issues necessary for disaster management. To adequately respond to a natural disaster, it is necessary to integrate a multitude of data sets, for which many institutions are responsible. Spatial data infrastructure (SDI) can solve the problem of accessibility by creating a framework for their sharing [9].

Simultaneously, institutions involved in the community for disaster management, as the SDI participants, have a legal obligation to collect and maintain the data sets for which they are competent. Assuming that each institution does its job conscientiously then, up-to-date spatial data sets can be expected to be available to decision-makers in the event of natural disasters.

2 THE ROLE OF SPATIAL DATA INFRASTRUCTURE IN DISASTER MANAGEMENT

2.1 INfrastructure for Spatial InfoRmation in Europe (INSPIRE)

INSPIRE (INfrastructure for Spatial InfoRmation in Europe) is an initiative launched to establish a European Spatial Data Infrastructure (ESDI) [10]. This initiative calls on the Member States of the European Union (EU) to publish their geographic data on the geoportal and gradually harmonize it. To support the integration of national infrastructures into INSPIRE, members should allow access to their infrastructure through INSPIRE-geoportals and other access points. INSPIRE is based on spatial data infrastructures established and implemented by the EU Member States. It covers 34 topics related to space data (Tab. 1). The Directive entered into force on 15 May 2007 and is planned to be implemented in phases, with full implementation by 2021 ([11, 12]).

Table 1 Three groups spatial data topics of INSPIRE Directive [11]

Annex 1	Annex 2	Annex 3
• Addresses • Cadastral • Parcels • Geographical Grid Systems • Hydrography • Transport Networks • Administrative Units • Coordinate Reference Systems • Geographical Names • Protected Sites	• Elevation • Land Cover • Geology • Orthoimagery	• Agricultural and Aquaculture Facilities • Bio-geographical Regions • Buildings • Energy Resources • Environmental Monitoring Facilities • Habitats and Biotopes • Human Health and Safety • Meteorological Geographical Features • Mineral Resources • Oceanographic Geographical Features • Natural Risk Zones • Population Distribution and Demographics • Production and Industrial Facilities • Sea Regions • Statistical Units • Soil • Species Distribution • Land Use • Utility and Governmental Service

The main principles of the INSPIRE Directive can be implement ([13, 14]):

1) Data shall be collected once and maintained at the level at which it is most effective.
2) Allow spatial data from different sources to be combined and shared among users and applications.
3) Spatial data collected at one level of the management structure can be shared at all levels.
4) Spatial data should be available under conditions that do not limit their extensive use.
5) Enabling easy detection of the required spatial data, knowing the conditions of their use.
6) Spatial data should be easy to understand, interpret, and should be visualized in a user-friendly manner.

2.2 Spatial Data Infrastructure (SDI)

The Spatial Data Infrastructure (SDI) is a set of technologies, measures, standards, implementing rules, services, human capacity, and other factors that enable the effective aggregation, management, and maintenance of spatial data sharing to meet national and European needs (Fig. 2 and 3).

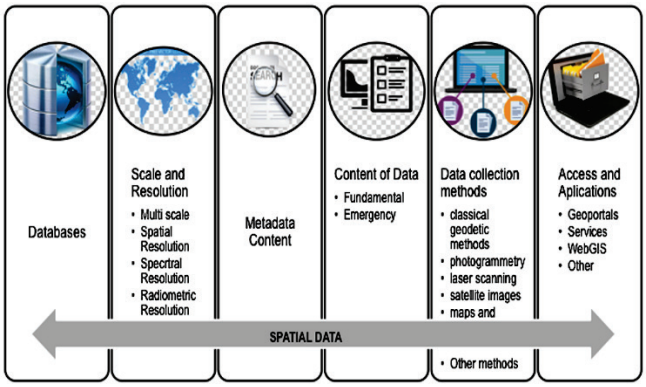


Figure 2 Spatial data and SDI

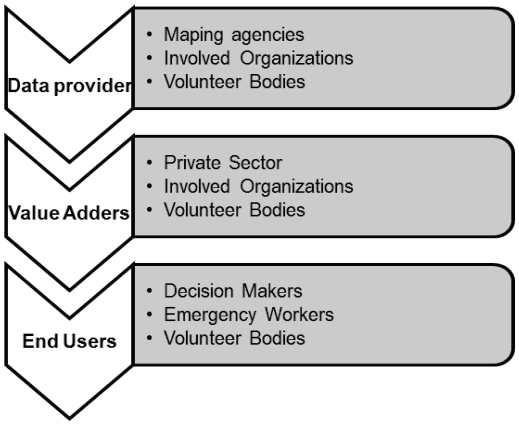


Figure 3 Scheme of connection of human capacities of different specialties in SDI

The purpose of establishing SDI is to streamline spatial data collection and standardize them to be networked and used well. Linking different spatial data types and their interoperability will enable users to conduct complex searches and analyze, and connect to spaces.

Thus, the preconditions for modern and efficient management of space and spatial resources will be realized, which directly stimulates and increases economic growth ([15, 12]).

In general, the Spatial Data Infrastructure establishment implies creating an environment that will enable a wide range of users to access, retrieve, and securely share spatial data. By implementing SDI, users save resources, time, and effort around collecting new datasets by avoiding duplication of costs related to data production and maintenance and have the ability to integrate their own data with other datasets. SDI implies integrating spatial data of different institutions and organizations, which is based on cooperation and partnership. Using SDI, effective natural and other disaster management model can be developed (Fig. 4).

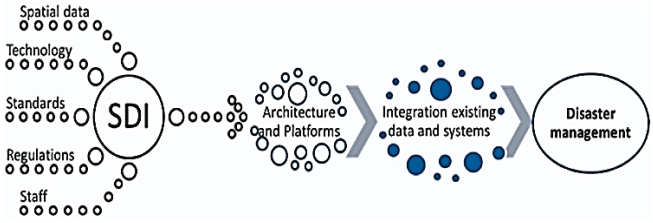


Figure 4 Relationship between SDI and Disaster management

Bosnia and Herzegovina (B&H) is not a member of the European Union, and the implementation of the INSPIRE Directive is not binding on it. However, the importance of INSPIRE principles for the advancement of the economy and other areas of society as a whole is recognized. It has established two SDI Geoportals (for Federation B&H and Republika Srpska) and services through sharing data with SDI subjects (only a few services and data sets). Accordingly, the Government of Federation B&H has adopted the Regulation on the SDI Federation B&H, appointed the Council members, and adopted the SDI Strategy. The Federal Administration for Geodetic and Property Affairs has appointed as the contact point of the SDI in Federation B&H.

2.3 Spatial Data Sharing

It is necessary to create an appropriate legal and business framework with the mandatory application of technical rules to create an efficient environment (virtual and real) for sharing spatial data between different institutions. There are different spatial data sharing models, which increase the availability and access to data of users of public institutions (state, federal, cantonal, municipal, and other institutions). No matter which model of sharing spatial data is adopted, it is necessary to previously implement legal, organizational, semantic, and technical interoperability. Natural disaster management involves the easy discovery, access, and use of spatial and non-spatial data defined by crucial data sets. For each spatial data set, which is considered crucial, defining the legal framework and data management procedures is necessary. That includes metadata about the frequency: of data updates, data set sources and data quality assurance. Data sharing is enabled through a web service. Thus, using data is simplified, and available time in protecting against natural disasters is spent more efficiently.

3 DEFINING KEY DATA SETS FOR NATURAL DISASTER MANAGEMENT

Unfortunately, there is still no appropriate database model on natural and other disasters in Bosnia and Herzegovina. Therefore, a proposal of key data sets for natural disaster management, based on INSPIRE topics, is proposed here. According [16] there are four group key datasets for natural disaster management:

1) Hazard
2) Vulnerability

3) Risk[1]
4) Exposed[2] [16].

Table 2 Datasets and INSPIRE topic [11] (rearranged table)

Group	Key Datasets	INSPIRE topic
Hazard	Watershed boundaries	Hydrography
	Water bodies	Hydrography
	Soil type	Soil Natural Risk Zone
	Flood hazard maps	Natural Risk Zone; Hydrography
	Meteorological gauge data	Meteorological Geographical Features Hydrography
	Flood protection measures	Hydrography – Hydro Physical Waters Natural risk zone
	Seismic hazard map	Meteorological Geographical Features Natural risk zone Geology
	Site conditions map	Geology, Soil
	Wind	Meteorological Geographical Features Natural risk zone
	Historical records of significant natural hazard events in the country	Natural Risk Zone
	Environmental hazardous activities	Natural risk zone
	Contaminated sites	Natural risk zone
Exposed	Land Use	Land Use
	Population	Population Distribution and Demographics
	Economic activities	Production and Industrial Facilities
	Company registers	Production and Industrial Facilities
	Buildings	Buildings
	Agricultural production	Agricultural and Aquaculture Facilities
	Critical infrastructures	Transport Network Utility and Governmental Service Hydrography - 'Hydro - Physical Waters' Buildings
	Expected growth of population density	No topic
	Expected growth of GDP	No topic
	Cultural Heritage	Buildings
	Environment	Protected sites
Vulnerability	Direct Economic vulnerability	Natural risk zone
	Indirect Economic vulnerability	Natural risk zone
Risk	Risk indicators from previous studies	Natural risk zone
	Risk assessment	Natural risk zone
	Historical Impacts on exposure	Natural risk zone

To these groups should be added a group named basic data sets, which are not directly related to natural disasters, which include:

- Reference coordinate system,
- Topographic bases (maps, digital orthophotos, satellite images, laser scanning of the terrain),
- Digital terrain model,
- Administrative units,
- Geographical names and
- Landcover.

The proposal of crucial data sets according to the division of groups and their coverage of INSPIRE topics are presented in Tab. 2.

Based on the defined key data sets and INSPIRE specifications for the mentioned INSPIRE topic, it is possible to create an appropriate data model that will be used for planning protection against natural disasters and effective action during natural disasters. Data from crucial spatial data sets should be described on the SDI Geoportal, and data access provided through a web service with previously signed spatial data sharing agreements and data use agreements.

4 EXAMPLE OF DETERMINING SECTIONS OF MAJOR ROADS EXPOSED TO FLOOD RISK

This paragraph proposes a technique for the development of a GIS browser. It offers an example of a thematic map for identifying critical sections of the Federation of Bosnia and Herzegovina's major roads exposed to natural flood disasters that can be used for flood risk management. Integration of collected data into free QGIS software, allowing spatial data to be analysed and visualized.

Three data sets are grouped into layers loaded into GIS software, namely (Fig. 5):
1) Administrative boundaries with layers:
2) Road network
3) Rivers and flood lines.

The subject of research in this example will be major road sections in the Sava River Basin.

The rivers in Federation B&H that belong to the Sava River's catchment area are Una, Vrbas, Bosna, and Drina.
The layers of hazard and the layers of risk elements need to be identified at the beginning. The layer of "Sava Flood 100Y" is classified as a hazard layer, while the layer of the "Main Road Network" is defined as a layer representing elements exposed to such hazards (Fig. 5).

As the road network is of the same (major) category, there was no need to classify the road network, while the flood lines were classified into different water-level grades, as follows:
- Low risk: 0 - 1000 mm
- Medium risk: 1001 - 2000 mm
- High risk: > 2000 mm.

[1] Risk is the combination of the consequences of an event (hazard) and the associated likelihood/probability of its occurrence [17].

[2] Exposure. People, property, systems, or other elements present in hazard zones, thereby subject to potential losses [2].

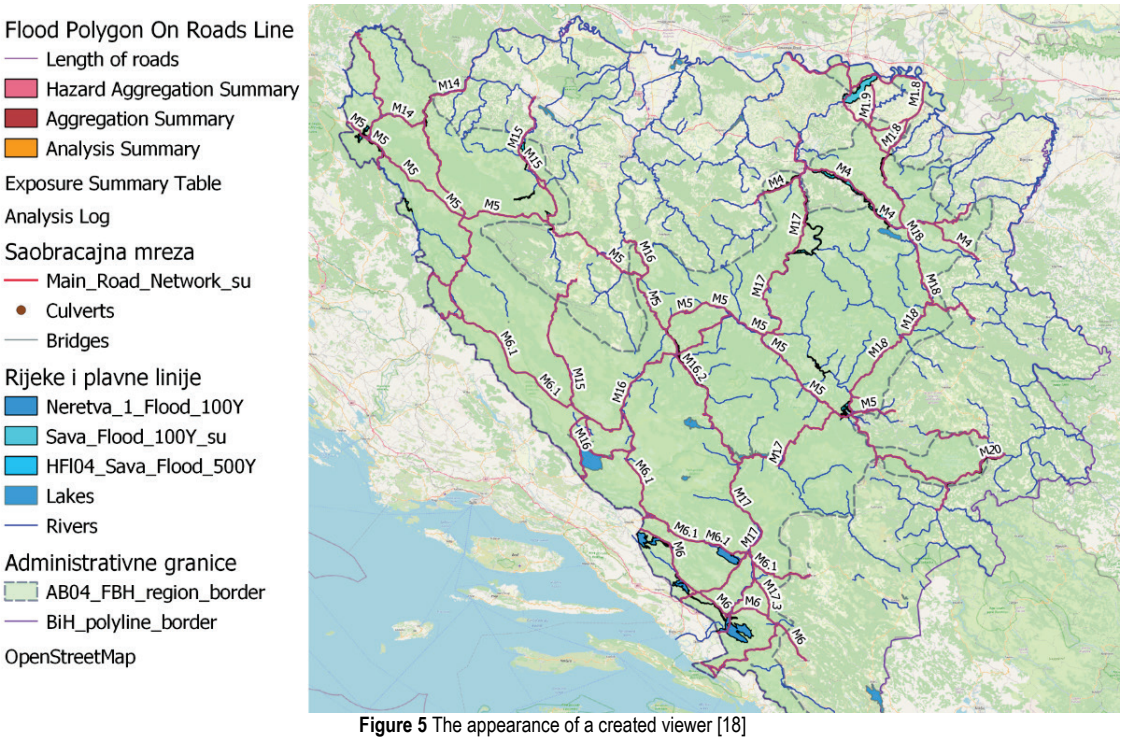


Figure 5 The appearance of a created viewer [18]

The program add-on "InaSAFE" has been used to determine the critical road sections. These road sections that overlap with the Sava River Basin flood lines (for 100 years return period). A thematic flood risk management map and the results of the data analysis are displayed in numerical and graphical form (Figs. 6, 7, 8, and 9).

InaSAFE

Analysis question

In the event of a Flood, what length of Roads might be affected?

General report

Estimated length of roads affected per hazard zone

Hazard Zone	Length (m)
High	6,300
Medium	799
Low	125,000
Total Exposed	132,000

Roads	Length (m)
Affected	7,100
Not Affected	125,000
Not Exposed	1,965,000

Figure 6 Estimated length of roads affected by flood event

It can be found (Fig. 7) that the road route M4 is subject to a high flood risk of 4.7 km in length (Fig. 8). The M20 road exposed to medium risk in the length of 0.8 km, while the M5 road in the length of 52.2 km and the M15 in the length of 45.5 km are the exposed to low risk.

Analysis detail

Estimated length of roads (m) affected by road type

Road type	Affected			Not affected		Total not exposed	Total
	High	Medium	Total affected	Low	Total not affected		
M15	0	0	0	45,500	45,500	196,000	242,000
M14.1	0	0	0	14,500	14,500	45,600	60,000
M16	178	0	178	0	0	114,000	114,000
M16.3	0	0	0	0	0	3,300	3,300
M19.2	0	0	0	0	0	28,600	28,600
M4	4,700	0	4,700	0	0	122,000	126,000
M1.8	789	0	789	0	0	70,500	71,300
M5	0	0	0	52,200	52,200	360,000	413,000
M11	0	0	0	752	752	8,500	9,200
M20	0	799	799	864	864	32,800	34,500
M16.4	141	0	141	0	0	39,000	39,200
M1.9	0	0	0	0	0	32,200	32,200
M17	6	0	6	6,400	6,400	217,000	223,000
M18	0	0	0	0	0	179,000	179,000
M16.2	463	0	463	0	0	69,400	69,800
M14.2	0	0	0	228	228	151,000	151,000
M6.1	0	0	0	0	0	160,000	160,000
M14	0	0	0	4,500	4,500	66,400	70,900
M18.1	0	0	0	0	0	46,300	46,300
M4.2	0	0	0	0	0	27,000	27,000
Total	**6,300**	**799**	**7,100**	**125,000**	**125,000**	**1,965,000**	**2,097,000**

Figure 7 Estimated length of roads affected by road route

The M4 road (the valley of the river Bosna and its tributaries Spreča) is a more densely populated area in the Federation of Bosnia and Herzegovina with the most significant industrial capacity, so often increasing watercourses and overflows result in endangering residential and commercial buildings and traffic interruption.

A thorough review of the identified road sections recommending steps at all flood risk management stages would be the next step. In all phases of the comprehensive flood risk management cycle, data read from the thematic map can be used: prevention, protection, awareness, readiness, and recovery.

5 CONCLUSION

Growth of the world population accompanied by urbanization and increased pressures on natural resources, and the process of land conversion in combination with natural hazards lead to increased vulnerability, both people and material goods [19]. Viewed from this angle, effective management of disasters is crucial. Effective disaster management involves managing a range of activities that begin with mitigating vulnerability and the adverse effects of disasters, increasing people's readiness to provide emergency assistance, and actively participating in disaster recovery - physical reconstruction and restoring the quality of life of the community. For the effective implementation of these activities, it is necessary to have easy access to reliable spatial and other information, which needs to be integrated. Since there are many data sets whose collection and maintenance are the responsibility of various public institutions, there are significant problems in their detection and sharing. The establishment of a Spatial Data Infrastructure (SDI) creates a basic framework for sharing up-to-date spatial data accessible to the broader community and contributes to better management of natural disasters. Since Bosnia and Herzegovina tend to join the European Union, the procurement, collection, preservation, and management of IT-based geo-data sets contribute to the need for accelerated standardization and harmonization of the geo-data sets with EU regulations in the INSPIRE Directive [18].

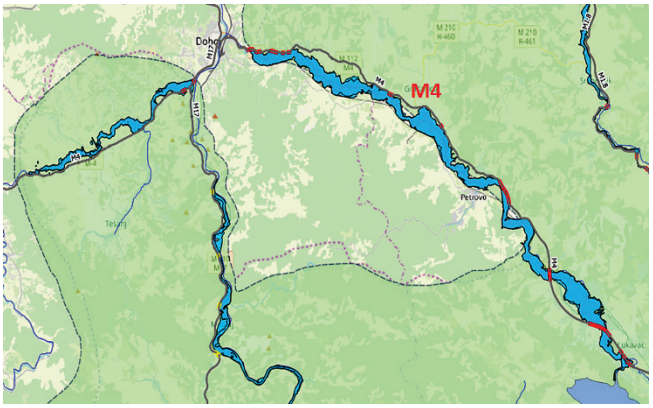


Figure 8 Endangered high-risk sections on the M4 road - the area of the city of Doboj

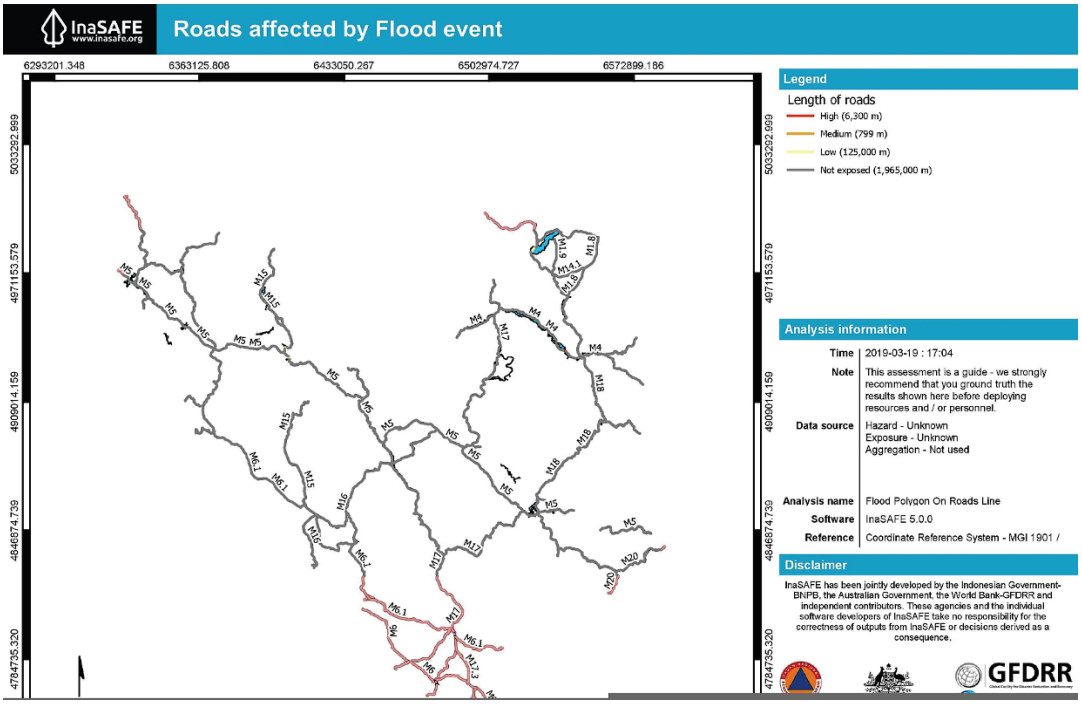


Figure 9 Risk road sections on the Sava River Basin area of Federation B&H

6 REFERENCES

[1] FEMA (1997). NEHRP Guidelines for the Seismic Rehabilitation of Buildings. Report No. 273, Federal Emergency Management Agency, Washington DC.

[2] UNISDR (2009). United Nations International Strategy for Disaster Reduction. Geneva, Switzerland. https://www.uclg.org/sites/default/files/7817_unisdrterminologyenglish.pdf

[3] Benson, C. & Clay, E. (2004). Understanding the Economic and Financial Impacts of Natural Disasters. *Disaster Risk Management Series*, no. 4. Washington, DC: World Bank. © World Bank. https://openknowledge.worldbank.org/handle/10986/15025 License: CC BY 3.0 IGO. https://doi.org/10.1596/0-8213-5685-2

[4] Misonali, R. & McEntire, D. (2008). *Rising Disasters and Their Reversal: An Identification of Vulnerability and Ways to Reduce It*. Disaster Management Handbook. J. Pinkowski. Boca Raton, CRC Press. https://doi.org/10.1201/9781420058635.ch2

[5] Sutanta, H. (2012). Spatial planning support system for an integrated approach to disaster risk reduction. *PhD thesis*, Centre for Spatial Data Infrastructures & Land Administration, Department of Infrastructure Engineering, The University of Melbourne. https://minerva-access.unimelb.edu.au/handle/11343/37854

[6] Službeni glasnik BiH br. 86/09 (2009). Metodologija za izradu procjene ugroženosti Bosne i Hercegovine od prirodnih ili drugih nesreća metodologiju za izradu procjene ugroženosti Bosne i Hercegovine od prirodnih ili drugih nesreća, http://www.msb.gov.ba/dokumenti/metodBOS.pdf (in Bosnian)

[7] Džebo, S., Šarić, A., Reeves, S., Ljevo, Ž., & Hadžić, E. (2020) Flood Impact and Risk Assessment on the Road Infrastructure in Federation of Bosnia and Herzegovina. In: Advanced Technologies, Systems, and Applications IV. *Proceedings of the International Symposium on Innovative and Interdisciplinary Applications of Advanced Technologies (IAT 2019)*. Lecture Notes in Networks and Systems, vol 83. Springer, Cham. https://doi.org/10.1007/978-3-030-24986-1_22

[8] Jain, S. & McLean, C. (2004). A Framework for Modeling and Simulation for Emergency Response. *Proceedings of the 2003 Winter Simulation Conference*, New Orleans, Louisiana, USA. https://doi.org/10.6028/NIST.IR.7071

[9] Mansouriana, A., Rajabifardb, A., & Javad Valadan Zoeja, M. (2005). SDI conceptual modeling for disaster management. *ISPRS Workshop on Service and Application of Spatial Data Infrastructure, XXXVI (4/W6)*, Oct. 14-16, Hangzhou, China. https://www.researchgate.net/publication/228634666_SDI_conceptual_modeling_for_disaster_management

[10] EC (2007). European Commission: DIRECTIVE 2007/2/EC of the Europian Parliament and of the Council: establishing an infrastructure for spatial information in the Community (INSPIRE), Brussels.

[11] Ključanin, S., Rossello, L., & Traverso, S. (2019). ERRA IPA DRAM Manual and Guidelines for Data Experts. https://www.researchgate.net/publication/339508648_ERRA_IPA_DRAM_Manual_and_Guidelines_for_Data_Experts

[12] Ključanin, S., Poslončec-Petrić, V., & Bačić, Ž. (2018). *Osnove infrastrukture prostornih podataka*. Dobra knjiga, Sarajevo. Bosna i Hercegovina. (in Bosnian)

[13] DGU (2008). Nacionalna infrastruktura prostornih podataka i INSPIRE, Državna geodetska uprava Republike Hrvatske, Zagreb. (in Croatian)

[14] Poslončec-Petrić, V. (2010). Distribucija prostornih podataka za potrebe službene kartografije Republike Hrvatske. *Doktorska disertacija*, Geodetski fakultet, Zagreb. (in Croatian)

[15] Poslončec-Petrić, V., Cetl, V., Babić, K. (2011). Uspostava infrastrukture prostornih podataka u Hrvatskoj. *Građevinar, 63*(12), 1087-1093. Retrieved from https://hrcak.srce.hr/75960 (in Croatian)

[16] https://inspire.ec.europa.eu/documents/Data_Specifications/INSPIRE_DataSpecification_NZ_v3.0RC2.pdf

[17] https://ec.europa.eu/echo/files/about/COMM_PDF_SEC_2010_1626_F_staff_working_document_en.pdf

[18] Ključanin, S., Džebo, S., Drugovac, M., & Bilalagić, I. (2020) Use of GIS Viewer for Flood Risk Management on the Main Road Network in the Federation of Bosnia and Herzegovina. In: *Advanced Technologies, Systems, and Applications IV - Proceedings of the International Symposium on Innovative and Interdisciplinary Applications of Advanced Technologies (IAT 2019)*. Lecture Notes in Networks and Systems, vol 83. Springer, Cham. https://doi.org/10.1007/978-3-030-24986-1_21

[19] Hadžić, E., Ključanin, S., & Milišić, H. (2018). Significance of Spatial planning and GIS technology in reducing natural disaster effects. *Forth Scientific-professional Conference Security and Crisis Management - theory and practice "SeCMan2018" Proceeding, Regional association for safety and crisis management (RASEC) and S4 Global security*, 139-147.

Authors' contacts:

Slobodanka Ključanin, PhD, Associate Professor
(Corresponding author)
University of Bihać - Technical Faculty,
Dr. Irfana Ljubijankića b.b., 77000 Bihać, Bosnia and Herzegovina
E-mail: slobodanka63@yahoo.com

Milan Rezo, PhD, Assistant Professor
University North, University Center Varaždin,
Jurja Križanića 31b, 42 000 Varaždin, Croatia
E-mail: milan.rezo@unin.hr

Suada Džebo, PhD, Assistant Professor
University of Sarajevo - Faculty of Civil Engineering,
Patriotske lige 30, 71000 Sarajevo, Bosnia and Herzegovina
E-mail: suada.dzebo.gf@gmail.com

Emina Hadžić, PhD, Full Professor
University of Sarajevo - Faculty of Civil Engineering,
Patriotske lige 30, 71000 Sarajevo, Bosnia and Herzegovina
E-mail: eminahd@gmail.com

ISSN 1846-6168 (Print), ISSN 1848-5588 (Online)
https://doi.org/10.31803/tg-20210302210045

Original scientific paper

Numerical and Experimental Vibration Analysis of a Steam Turbine Rotor Blade

Marko Katinić*, Marko Ljubičić

Abstract: Damage to the rotor blade of a steam turbine is a relatively common problem and is one of the leading causes of sudden and unplanned shutdowns of a steam turbine. Therefore, the high reliability of the rotor blades is very important for the safe and economical operation of the steam turbine. To ensure high reliability, it is necessary to perform a vibration analysis of the rotor blades experimentally and in a computer environment. In this paper, a modal analysis was performed on the twisted blade of the last stage of the turbine in the Ansys software. The results of the modal analysis of the stationary rotor blade were compared with the results obtained by the bump test, which confirmed the numerical model of the blade. A modal analysis of a rotating rotor blade was performed on the same numerical model, and Campbell diagrams were plotted to determine the critical speeds.

Keywords: Campbell diagram; critical speeds; modal analysis; natural frequencies; rotor blades; vibration modes

1 INTRODUCTION

Steam turbines are rotary machines that are used extensively in thermal power plants and the process industry. The pursuit of higher power output leads to increasing turbine operating speeds. However, higher operating speeds pose a greater challenge to the turbine designers regarding the dynamic machine behavior. Also, the turbine rotor should be balanced in a higher class according to the ISO 1940 standard [1], which ensures an acceptably low level of vibrations caused by the rotor unbalance.

Rotor blades of steam turbines operate in relatively difficult conditions. During operation, they are subjected to high tensile stresses, but resonant vibrations are also common. They are the cause of bending stresses of the blade. In addition to bending and tensile stresses, in high pressure areas the blades are exposed to high working medium temperatures. In low pressure areas blades are subjected to moist steam which causes their erosion. Fatigue caused by alternating stresses or a single stress greater than the allowable one can cause the blade to failure. According to the appearance of the fracture surface, it can be concluded which type of fracture it is (due to fatigue or due to a stress greater than allowed). The main cause of failure of steam turbine blade is high cycle fatigue. [2] An example of rotor blade fracture at the root as a result of high-cycle fatigue is shown in Fig. 1. [3]

Rotor blade fractures caused by static stresses rarely occur in practice. The most common cause of steam turbine failures are fractures of rotor blades due to dynamic stresses. Dynamic stresses are the result of vibrations of the rotor blades, which after a certain number of cycles can lead to fatigue fracture of the blades. Stress risers and corrosion significantly reduce the fatigue strength of the blades, resulting in initial cracks that propagate due to dynamic stresses. When the crack extends so deeply that the stresses, in the reduced cross-section of the blade, exceed the strength of the material, a final violent blade fracture occurs. It is especially dangerous when the rotor blades of the last stages of the energy steam turbine, which are long and have a large mass, failure. Due to the action of centrifugal force, the fracture of such blades causes them to fly out and break through the thick-walled turbine casings, which leads to catastrophic damage. [4]

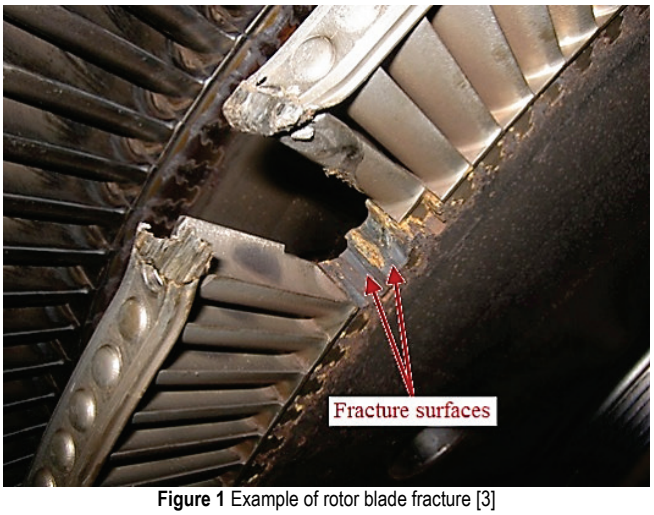


Figure 1 Example of rotor blade fracture [3]

A vibration is any movement of the body that is repeated. Avery body that possesses its own mass and elasticity has the ability of oscillatory motion. The vibrations of the turbine rotor blades can be free and forced. The rotor blades vibrate in bending and torsion modes. Bending vibrations can be in tangential (in the plane of the rotor bladed disc) and axial (perpendicular to the plane of the rotor bladed disc) directions. The torsional vibrations of the blades occur around their longitudinal axes.

Turbine blades vibrate due to several of reasons. The most common cause is a periodic force that excites vibrations. Periodic forces, which excite the vibrations of the rotor blades, can have an aerodynamic and mechanical character. Purely aerodynamic causes of vibration are due to the flow of steam through the stator channels and the local flow of steam through the join of the upper and lower halves of the diaphragm. The frequencies of the periodic excitation force generated by the flow of steam through the stator channels are zn and $2zn$ (z is the number of stator blades, and n is the rotor speed in revolutions per second). [5] The mechanical sources of blade vibrations are due to the

vibration of the turbine rotor and the vibration of the discs carrying the rotor blades. The frequencies of the periodic forces in this case are the first and higher harmonics of the rotor speed. In some cases, the so-called self-excited vibrations may also occur. But self-excited vibrations in turbine rotor blades are rare. When the frequency of the excitation force coincides with the natural frequency of the rotor blades, resonance occurs, which is manifested by an increase in the amplitude of vibrations and consequently by an increase in dynamic stresses. Unfortunately, such a phenomenon can ultimately lead to failure of the rotor blades and catastrophic damage of the turbine.

Before the analysis of the rotor blade, in this paper, the modal analysis of the cantilever beam has been performed, for which the natural frequencies and the corresponding vibration modes have been determined. In order to verify the numerical model, the analysis has been done analytically and numerically for the non-rotating (stationary) and rotating cantilever beam. The results of the analytical analysis have been compared with the numerical results obtained using the Ansys software package. [6]

After the numerical and analytical analysis of the cantilever beam, the numerical modal analysis of the rotor blade of the last turbine stage has been performed. The rotor blade is twisted, and the shape of the blade profile changes with the height of the blade. Due to the complexity of the blade shape, the model will be created in the SolidWorks software package. [7] Numerical modal analysis was performed separately for non-rotating (stationary) and rotating blade.

For additional verification of the numerical model, the results of the numerical analysis for non-rotating blade were compared with the experimental results obtained by the bump test. Then the results of the numerical modal analysis of the non-rotating and rotating blades was compared to determine the influence of turbine rotor speed on the blade natural frequencies. Finally, Campbell diagram was done to determine the critical speeds. [8]

2 NUMERICAL MODEL VERIFICATION

2.1 Modal Analysis of the Cantilever Beam

A numerical modal analysis of the cantilever beam shown in Fig. 2 was performed. The dimensions and properties of the beam are given in Tab. 1.

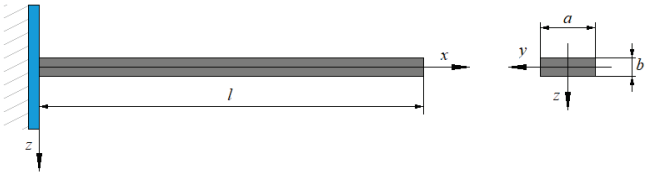


Figure 2 Cantilever beam

Table 1 Cantilever beam properties

Modulus of elasticity	E	200 GPa
Density	ρ	7850 kg/m^3
Poisson's ratio	ν	0,3
Cantilever beam length	l	0,6 m
Cantilever beam height	b	0,01 m
Cantilever beam width	a	0,024 m

The numerical modal analysis of the non-rotating beam was performed first. The analysis was performed in the Ansys software package. The results of the numerical modal analysis were compared with the analytical results obtained using the expression from [9] (Tab. 2). As can be seen from Tab. 2, the largest deviations are below 1%, which confirms the validity of the numerical model.

Table 2 Comparison of analytical and numerical analysis results of the cantilever beam

Mode	Natural frequency, Hz		Deviation %
	Analytical	Numerical	
Transverse mode y-axis	22,65	22,69	0,18
	141,94	142,00	0,04
	397,46	396,80	0,17
	774,65	775,34	0,09
Transverse mode z-axis	54,35	54,35	0,00
	340,65	338,09	0,75
Torsional mode	868,88	866,45	0,28

A numerical modal analysis of the rotating cantilever beam was then performed. A prestressed modal analysis is performed that involves the influence of centrifugal force due to rotation. This is achieved by performing a static structural analysis first on the rotating cantilever beam, followed by the modal analysis. The result of static analysis are stress and strain fields due to inertial loading. The inertial load is due to the rotation of the beam about the y-axis at an angular speed Ω. The calculation was performed for rotational speeds of 25π rad/s and 50π rad/s. The obtained stress fields are further used as input to the modal analysis. The results of the numerical modal analysis were compared with the semi-analytical results obtained using the following expression [10]:

$$\omega_i = \sqrt{\omega_{in}^2 + \Omega^2 \cdot (c_i - \sin^2\psi)}, \tag{1}$$

where ω_{in} is the i^{th} natural frequency of the non-rotating cantilever beam; ψ is angle of the beam inclination in relation to the axis of rotation; c_i is a constant that depends on the vibration mode. A comparison of these results is shown in Tab. 3. The largest deviations are below 1% which validates the numerical model. In this way, confidence in the numerical model of the cantilever beam is achieved.

Table 3 Comparison of analytical and numerical analysis results of the rotating cantilever beam

Mode	Natural frequency, Hz			
	Ω = 25π rad/s		Ω = 50π rad/s	
	Analytical	Numerical	Analytical	Numerical
Transverse mode y-axis	25,17	25,03	31,56	31,36
	153,52	153,57	183,96	183,93
	410,51	409,79	447,35	446,25
	788,66	789,23	829,28	829,32
Transverse mode z-axis	60,88	60,79	77,05	76,83
	346,54	343,97	363,64	361,01

2.2 Modal Analysis of the Non-Rotating Twisted Rotor Blade

The calculation of natural frequencies and vibration modes was performed on a twisted rotor blade of the last

stage of a steam turbine with a maximum power of 20 MW. The turbine is condensing controled extraction, and it drives an electric generator. The rotation speed of the turbine rotor is 3000 rpm. The number of rotor blades of the last turbine stage is 90, and the number of belonged nozzles is 74. The geometry of the blade model was prepared in the SolidWorks 2018 software package (Fig. 3). [11]

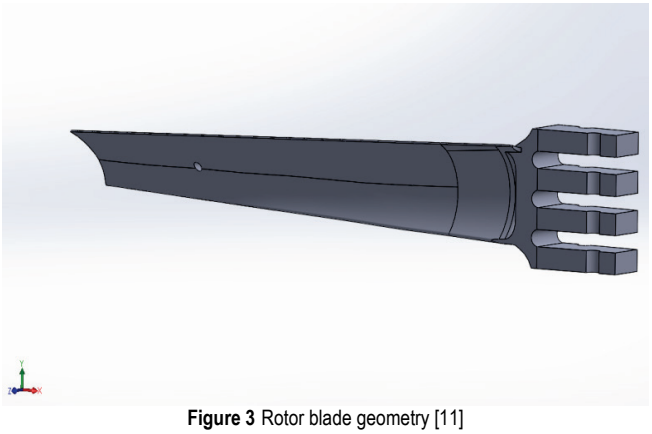


Figure 3 Rotor blade geometry [11]

The above model was imported in ANSYS 17.2 for modal analysis. The material of the blade is high temperature steel X22CrMoV12-1 whose properties are given in Tab. 5. [11]

Table 4 Rotor blade material properties [11]

Steel density	7700 kg/m^3
Modulus of elasticity	216 GPa
Yield stress	675 MPa
Ultimate tensile strength	880 MPa
Poisson's ratio	0,28

The element mesh was generated using a three-dimensional 10-node finite element SOLID187 (Fig. 4). The mesh consists of 529418 finite elements and 768457 nodes. [11] All degrees of freedom on the multi fork root surfaces of the blade are constrained because they are firmly attached to the rotor disk. This finite element model was used to obtain the mode shapes and natural frequencies for the non-rotating turbine blade.

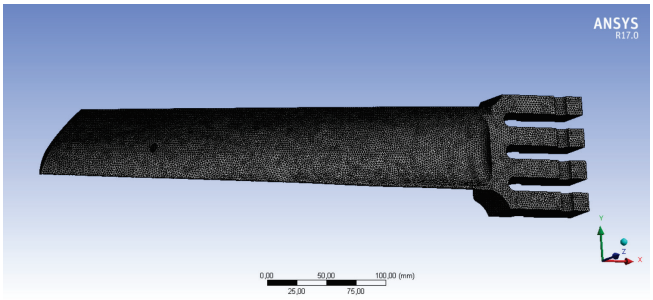


Figure 4 Generated finite element mesh [11]

The natural frequencies of the actual rotor blade were measured using a bump test (Fig. 5). The hits of a special hammer on the object generate impulse excitations in a wide range of frequencies, which excite a large number of natural modes of vibration. Prüeftechnick type VIBEXPERT II FFT analyzer and Prüeftechnick piezoelectric accelerometer type VIB 6.142 R were used to measure the frequency response. [11]

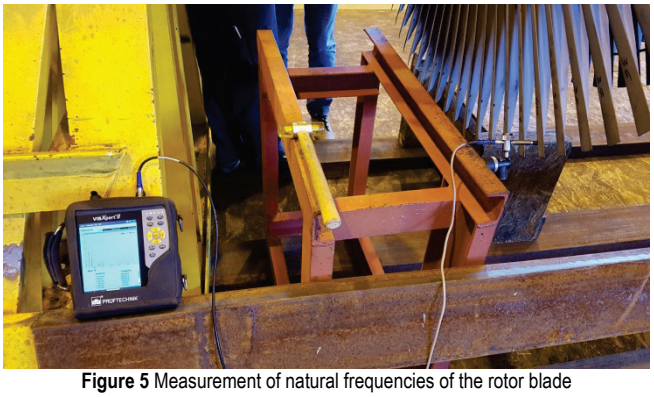


Figure 5 Measurement of natural frequencies of the rotor blade

A comparison of numerically calculated and experimentally measured natural frequencies of rotor blades is given in Tab. 5. [11] The deviations of the calculated and measured frequencies are acceptably low, which gives full confidence in the numerical model of the blade.

Table 5 Comparison of the results of numerical analysis and measurements on the non-rotating twisted blade [11]

Mode	Natural frequency, Hz		Deviation, %
	Numerical solution	Bump test	
1	190,96	191	0,02
2	362,75	363	0,07
3	789,93	789	0,12
4	953,66	1004	5,01
5	1311,50	1277	2,70

3 MODAL ANALSYS OF THE ROTATING TWISTED ROTOR BLADE

After the above verification of the numerical model, a modal analysis of the rotating blade could be performed. Similar to the case of the rotating beam, a static structural analysis of the blade rotating around an axis coinciding with the longitudinal axis of the rotor shaft was first performed. The blade rotation radius was 533 mm (radius of the rotor disc), and the rotational speed was $\Omega = 100\pi$ rad/s. The obtained stress fields are further used as input to the pre-stressed modal analysis. The results of the numerical modal analysis are given in Tab. 6. [11]

Table 6 Results of numerical analysis of the rotating twistd rotor blade [11]

Mode	Natural frequency, Hz
1	207,82
2	375,75
3	810,35
4	957,86
5	1329,00

Fig. 6 shows the first four modes of the turbine rotating blade. [11]

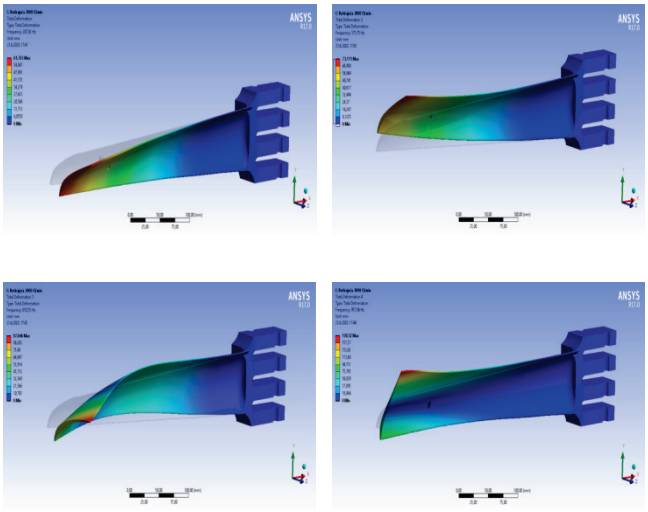


Figure 6 First four vibration modes of the rotating blade [11]

4 RESULTS AND DISCUSSION

Tab. 7 gives a comparison of the natural frequencies obtained by the numerical calculation for the non-rotating and rotating rotor blades. [11]

Table 7 Comparison of numerically calculated natural frequencies of non-rotating and rotating blades [11]

Mode	Natural frequency Hz	
	Non-rotating blade	Rotating blade
1	190,96	207,82
2	362,75	375,75
3	789,93	810,35
4	953,66	957,86
5	1311,50	1329,00

As can be seen from Tab. 7 the corresponding natural frequencies for the rotating blade are higher than for the non-rotating one. This is physically understandable because the centrifugal force, which results from the rotation, increases the stiffness of the blade. The centrifugal force has the greatest influence on the increase of the first natural frequency, to which the bending mode of vibration belongs (Fig. 6). The centrifugal force has the least effect on increasing the natural frequency of the 4th natural frequency, which is in fact a torsional vibration mode (Fig. 6). The stiffening effect depends on the rotational speed. This means that the natural frequencies depend on the rotational speed. This dependence is represented in the form of a Campbell diagram. The Campbell diagram is used to determine the so-called critical speeds. Critical speeds are the speeds at which the excitation frequencies coincide with the natural frequencies of the rotating structure (resonance phenomenon). The excitation frequency can be synchronous to the rotation speed (1X) or multiples of the rotation speed (2X, 3X, …). The excitation frequencies are plotted as straight lines in the Campbell diagram. The critical speed is the intersection of this straight line with the natural frequency curve.

Fig. 7 shows a Campbell diagram on which the straight lines of the first eight excitation harmonics are plotted. [11] The diagram (Fig. 7) shows that in the whole range of rotational speeds no natural frequency curve intersects the straight line 1X, 2X or 3X. The curve of the 1st natural frequency intersects the straight line 4X, so the critical speed of rotation is 330 rad/s. This critical speed is higher than the operating speed (314.16 rad/s) by 5%, which means that at the operating speed there will be no resonance of the blade caused by the 4th excitation harmonic. The straight lines 5X, 6X, 7X, and 8X intersect the 1st natural frequency curve at critical speeds that are lower than the operating speed of rotation. During the start or stop of the turbine, this speed range should be passed smoothly, without holding. The straight lines 7X and 8X intersect the curve of the 2nd natural frequency, so the critical speeds are 339.2 rad/s and 293.9 rad/s. The first critical speed is 8% higher than the operating speed, while the second critical speed is 7% lower than the operating speed. It follows that the resonance of the blade caused by the 7th or 8th excitation harmonic will not occur at the operating speed.

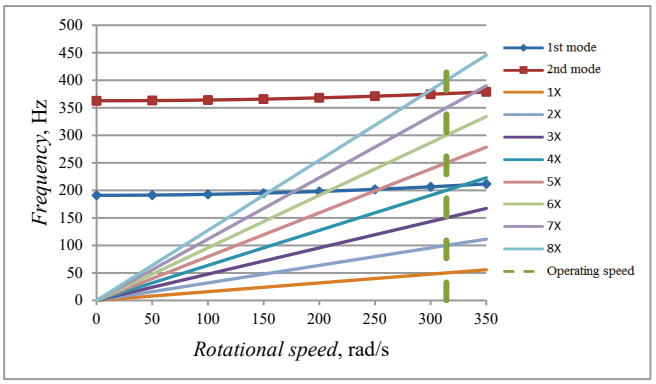


Figure 7 Campbell diagram for the first eight excitation harmonics [11]

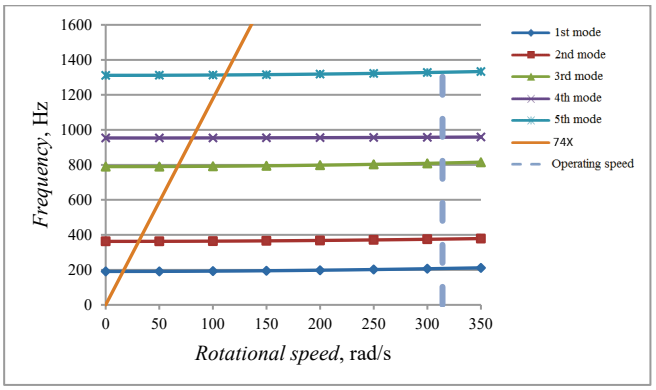


Figure 8 Campbell diagram for 74th excitation harmonic [11]

Excitation of rotor blade vibrations can be caused by steam flow from the nozzle channels. The flow of steam causes pressure oscillations behind each stationary blade. These oscillations are called nozzle wakes. Passing through the nozzle wakes the rotor blades experience a series of impulses. The frequency of these impulses is a product of the number of nozzles and the frequency of rotation. This is called nozzle passing frequency (NPF). Since the number of nozzles is 74, the excitation frequency is then 74X. Fig. 8 shows a Campbell diagram with a straight line 74X plotted. [11] It can be seen in the diagram that all the natural

frequency curves intersect the 74X straight line at different rotational speeds, which represent the critical speeds. All critical speeds are significantly lower than the operating speed. During the start or stop of the turbine, this speed range should be passed smoothly, without holding.

5 CONCLUSIONS

Determining the natural frequencies and the corresponding vibration modes of the steam turbine rotor blades is an important step in dynamic analysis. By knowing the natural frequencies, the occurrence of blade resonance, which could lead to blade fracture and turbine catastrophic failure, can be avoided. This paper shows that numerical modeling in the software package Ansys can successfully calculate the natural frequencies and vibration modes of the non-rotating and rotating blades. Confidence in the numerical model was confirmed by the results of measuring the natural frequencies of non-rotating blades by bump test. The confirmed numerical model could thus be applied to the analysis of a rotating blade, thus calculating its natural frequency values. Due to the influence of centrifugal force on the increase of blade stiffness, the natural frequencies of the rotating blade are higher than the corresponding natural frequencies of the non-rotating blade. Analysis of the Campbell diagram found that blade resonance would not occur at the turbine operating speed. Namely, all critical speeds are at speeds lower or higher than the operating speed.

6 REFERENCES

[1] ISO1940 (2003). Mechanical vibration – Balance quality requirements for rotors in a constant (rigid) state

[2] Ziegler, D., Puccinelli, M., Bergallo, B., & Picasso, A. (2013). Investigation of turbine blade failure in a thermal power plant. *Case Engineering Failure Analysis, 1*(3), 192-199. https://doi.org/10.1016/j.csefa.2013.07.002

[3] Katinić, M., Kozak, D., Gelo, I., & Damjanović, D. (2019). Corrosion fatigue failure of steam turbine moving blades: Case study. *Engineering Failure Analysis, 106*, 104136. https://doi.org/10.1016/j.engfailanal.2019.08.002

[4] Chowdhury, S. G., Das, G., Ray, A. K., Das, S. K., & Bhattacharya, D. K. (2003). Turbine blade failure in a thermal power plant. *Engineering Failure Analysis, 10*, 85-91. https://doi.org/10.1016/S1350-6307(02)00022-5

[5] Kostyuk, A. & Frolov, V. (1988). Steam and Gas Turbines, Mir Publishers, Moscow.

[6] Ansys Inc.: ANSYS 17.2

[7] Dassault Systèmes: Solidworks 2018

[8] Rieger, N. F. (1988). *Rotordynamics 2, Problem in Turbomachinery*. CISM - Udine, Springer – Verlag, Wien. https://doi.org/10.1007/978-3-7091-2846-6

[9] Singiresu, R. S. (2007). *Vibration of Continuous Systems.* John Wiley & Sons, Inc., Hoboken, New Jersey.

[10] Genta, G. (2005). *Dynamics of Rotating Systems,* Springer Science Business Media, Inc,. Torino. https://doi.org/10.1007/0-387-28687-X

[11] Ljubičić, M. (2020). Vibration analysis of steam turbine rotor blade. *Graduate Thesis*, Mechanical Engineering Faculty in Slavonski Brod. (in Croatian)

Authors' contacts:

Marko Katinić, PhD, Assistant Professor
(Corresponding author)
Mechanical Engineering Faculty, University of Slavonski Brod,
Trg I. B. Mažuranić 2, 35000 Slavonski Brod, Croatia
035/493417, marko.katinic@unisb.hr

Marko Ljubičić, Mag. Ing. Mech.
Mechanical Engineering Faculty, University of Slavonski Brod,
Trg I. B. Mažuranić 2, 35000 Slavonski Brod, Croatia
marko.ljubicic@unisb.hr

ISSN 1846-6168 (Print), ISSN 1848-5588 (Online)
https://doi.org/10.31803/tg-20210506103212

Original scientific paper

Technical Aspects of Web Photography as a Medium of Tourism Development

Petra Ptiček, Ivana Žganjar, Miroslav Mikota*, Mile Matijević

Abstract: Information and communication technology is an important factor for national, regional and local sustainable tourism development according to the long-term Croatian national strategic plan. New forms of information, such as web sites; new media, materials, political and social change, all influence tourists' decisions when choosing specific destinations. The aim of this research is to determine, based on the analysis of the tourism media campaign, the relationship between new communication trends and the application of photography as a medium that influences the experience when choosing a destination and the importance of crucial information factors on web pages based on their technical and visual characteristics.

Keywords: color; photography; tourism development; web pages

1 INTRODUCTION

Tourism relies on the application of new technologies' modern trends, innovations, and software solutions in order to meet the individual needs of tourists. The influence of changes in technology is reflected in the decision making regarding the promoted destination because of the tourists' need to choose the desired destination on their own. Therefore, marketing communication in the digital world is focused on creating a presence, a relationship and added value for consumers and services in tourism. The basic concept of integrated marketing communication is aimed at encouraging the user to go to the desired destination relying on the promotional message. With the development of new media, new promotion services are emerging, and the emphasis is on multimedia and interactivity. Combining services and applying the appropriate marketing strategy is reflected in making appropriate decisions. Photography and fast loading of content on tourist websites are an important element of advertising. Web sites have the ability to spread information in a very short time. Consequently, web sites in tourism have changed the way people research, gather information, make decisions and share their experiences. When choosing their destination, tourists search the internet to explore offers, accommodation, and useful tips from other tourists. In order to connect through web sites, in the most appropriate, informative, and interesting way, photographic images of the desired destinations have proven to be a key element in tourism promotion as a means of information exchange [1]. In the digital age, the importance of the visual comes to the fore because it will occupy the observer and involve them emotionally. Photography is necessary for the presentation of products, ideas, thoughts, services, and it attracts attention and directs the user to make decisions about their tourist experience. Today, when photographing advertising photography, the photographer is expected to have a wide range of knowledge, experience and fresh ideas. It is important to emphasize that advertising photography goes through extensive editing [2, 3]. Photography's indirect purpose is to realize the sale of the desired service. Consumers spend 80% of their time on the perception of photography, and 20% on the content of a text message, so it is necessary to realize the idea of the photographer on a perceptual level [4]. Perception is the process of receiving, processing and storing stimuli that builds an impression of a service. There is no simpler and more elegant way to influence the viewer other than using photography [5]. The goal of photography is to evoke emotions and feelings in the viewer that describe the product and service. Clear communication between the photographer and the viewer is necessary for photography to be successful [6]. Photography provides endless possibilities for expressing and experiencing emotions. That is precisely the reason why photography is an indispensable element when using visual media for the purpose of advertising in tourism. Photography, especially portrait photographic images, attracts attention, transmits information and enhances communication and understanding of the web site's tourist offerings, [7, 8]. Quality tourist web pages based on visual elements and professional photography can create a better user experience and spur the development of tourism. Previous research on the analysis of photographic images of human faces shows that their use contributes to the informativeness of the website. Research has shown that a smiling face, the face facing the camera, authenticity, and simple backgrounds are elements which draw attention to the content of web pages [9]. For this reason, the authors explore the visual content under the technical characteristics of web pages and that includes photography as a design element in a digital environment. Preliminary research was based on the presence of these elements: color, movement, photography and logos, and the use of symbols and their characteristics. Following the preliminary results, which support the hypothesis of the importance and role of photography as an element that attracts and retains the user on the website and increases the amount of information, the authors in this scientific research analyze photography as one of the most important multimedia components reflected in the tourists' destination selection based on the definition of the technical characteristics of the human face.

2 THE EXPERIMENT

In accordance with the web-based national presentation of tourism in the Republic of Croatia, the authors conducted a research on eleven websites defined at the national level.

The results of the scientific research show that facial photography affects the quality of the tourist website, creating a better user experience, Fig. 1.

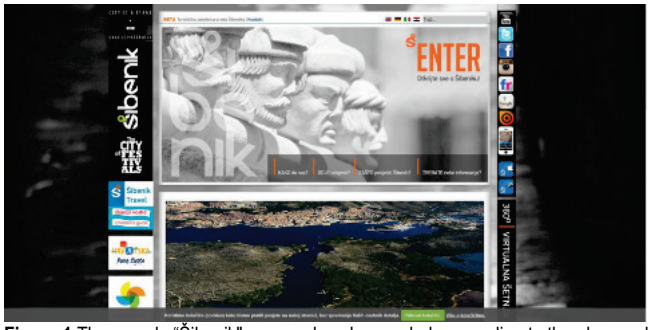


Figure 1 The sample "Šibenik" was analyzed as a whole according to the observed contents of the website: A-social networks; B- text ; C-central photography of the face; D-logo; E-Šibenik logo; F-navigation; G-picture above. Source: https://www.sibenik-tourism.hr

The statistical analysis in this phase of the research included all data from the empirical part of the research analyzed by the method of descriptive statistics. The survey, conducted on 150 participants, (75 male, 75 female participants, the average age 25), established a subjective assessment of the quality of the seen content based on the information and guidelines for tourism development while taking into consideration the user's needs. The statistical package STATISTICA 12.0 was used for statistical data processing. Samples were displayed on an ASUS PA27AC, HDR monitor and viewed at a distance of 650 mm from the screen. Observer reactions and the number of fixations required to perceive information were determined and measured using the Tobii Eye Tracker X60. The software used to conduct the test was Tobii Studio 3.2.1. The observers were placed in front of the monitor which was located in a separate room without additional lighting, according to the standard for graphic technology and professional photography ISO 3664:2009. At the beginning of each individual experiment, the respondents were explained the task and the content displayed on the monitor. At the end of the survey, the respondents filled out a questionnaire. During the experiment, using the Tobii Eye Tracker X60, the movement of the gaze was recorded on eleven samples, the time and number of fixations that the subject needed to notice the information were measured. In order to establish the way in which the participants viewed the samples, certain areas of interest were defined on each of the eleven samples according to their visual characteristics in such a way that each individual graphic element was considered a separate area of interest.

The analysis of the characterization of web page elements as an information and communication tool, and the statistical parameters of the respondents' evaluation of each web page shows that among the technical characteristics aimed at optimizing network tools intended for promotional activities, "Google Chrome", was rated as best, followed by "Mozilla Firefox", "Internet Explorer" and "Opera". Among social networks that enable interaction and networking, "YouTube" was rated as best, then "Facebook", then "Instagram" and "Twitter". The best rated element of visual features is photography, followed by dominant color, logo, and movement. The best rated product from the development perspective is the production group "sun and sea", followed by adventure and sports tourism, cultural tourism, gastronomy and oenology, nautical tourism, rural mountain tourism, ecotourism, cycling, and health tourism, while the lowest rated were golf and business visits.

The stated characteristics of the content of web pages as an information and communication tool in relation to the technical characteristics, visual characteristics and the presence of content from the perspective of development on web site sample "Šibenik" included areas of interest of respondents (Fig. 2). It also included the following design elements in the digital environment: central photography faces, picture 2, logo, logo 2, social networks, striking text, navigation bar, in relation to the samples that include the following areas of interest: picture 3, picture 4, logo 3, virtual walk / application, multilingualism, search engine.

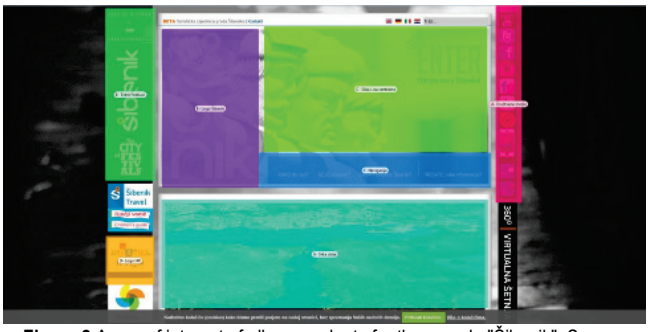


Figure 2 Areas of interest of all respondents for the sample "Šibenik". Source: https://www.sibenik-tourism.hr

The results show that participants who were offered visual content of web site samples based on web tools that offer more choices on how to use the content, rated it more accessible, informative and credible when planning and organizing trips, and the analysis based on Tobii Eye Tracker X60 showed that the website sample "Šibenik" includes the presence of visual information of new network tools and confirms the presence of visual information through seven areas of interest of the total observed. When viewing the sample, the main points of interest, visual entries of the participants to the web page are the central photography of the face, picture 2, logo, logo 2, social networks, striking text, navigation bar. The achievement of the goals defined on national level is based on the assumption that promotional activities tailored to end users, based on ease of access to information and credibility, positively reflect on their selection and decision-making process with direct impact on the economy. The analysis of the sample "Šibenik" based on application of new online tools for promotional activities confirms the hypothesis of contribution to the development of tourism as a strategic branch of the economy. Based on the analysis of the portrait photographic images on the referent website, the reference file size of the portrait photographic image digital record of 28.8 M was determined as the original digital record size. Digital biometric portrait photographic

image obtained by shooting with the digital Leica format Canon Eos 5DSR camera with the maximum resolution of 50 MP in Adobe RGB color space with correct white balance and correct exposure elements (exposure time 1/60 sec, lens aperture 5.6) determined by TTL for sensitivity of 100/21 ISO was taken. The TTL system was used segmentally on the skin color of the face. The Kaiser 1000 halogen reflector was used as the light source. The photographic image was saved in the finest JPG format (12) and loaded in Adobe Photoshop 2020 program where it was converted to the reproducible sRGB color space, and the file size was reduced from recorded to the reference size of 28.8 M. The photographic image was saved in the finest JPEG format and defined as the original. Defined original photographic image was degraded for the purposes of research by using the tools of Adobe Photoshop 2020 program.

The first degradation was performed by simulating the exposure change in the step of decreasing and increasing 1/3 of the lens aperture in the range of ± 1 lens aperture.
The second degradation was performed by changing the saturation in steps of ± 5 in the range ± 15.

The third degradation was performed by changing the color temperature by simulating the application of correction filters: WF (85), WF (LBA), WF (81), CF (80), CF (LBB), CF (82).

The fourth degradation was obtained by simulating the decrease in sharpness in the range of 10-60 with the change step of 10. The fifth degradation was obtained by saving the digital record of the original photographic image in four fineness of JPG records: low (1), medium (5), high (8), maximum (12).

Degradations 1-3 were performed in the same way on the Adobe Camera Raw color table, and degradations 4 and 5 on the ISO 12233 resolution table, which was previously, as the original resolution table, reduced from the file size 47,5MP to the reference 28,8 M. The original and degraded photographic images were evaluated by six experts in the field of photographic images by the simultaneous haploscopic (S) and memory (M) method of comparison in controlled conditions according to the standard for graphic technology and professional photography ISO 3664:2009. For the evaluation ASUS PA27AC calibrated monitor was used. Experts rated the degraded photographic images on the Lickert scale of 1-4 where rating 1 means completely unacceptable, 2 unacceptable, 3 acceptable and 4 completely acceptable degradation. Degraded photographic images were evaluated by experts according to the criteria of acceptability of changes in exposure, saturation, color temperature and sharpness (Fig. 3). For degraded color tables (degradation 1-3), using Adobe Photoshop 2020, L* a* b* values of standard light skin, dark skin and achromatic colors were determined, as well as average L* a* b* color values of average table color. For all observed colors, the total color change ΔE_{00} was determined. On the degraded resolution tables (degradation 5, 6), the resolution of the lines horizontally and vertically according to the image height (LW / PH) was determined.

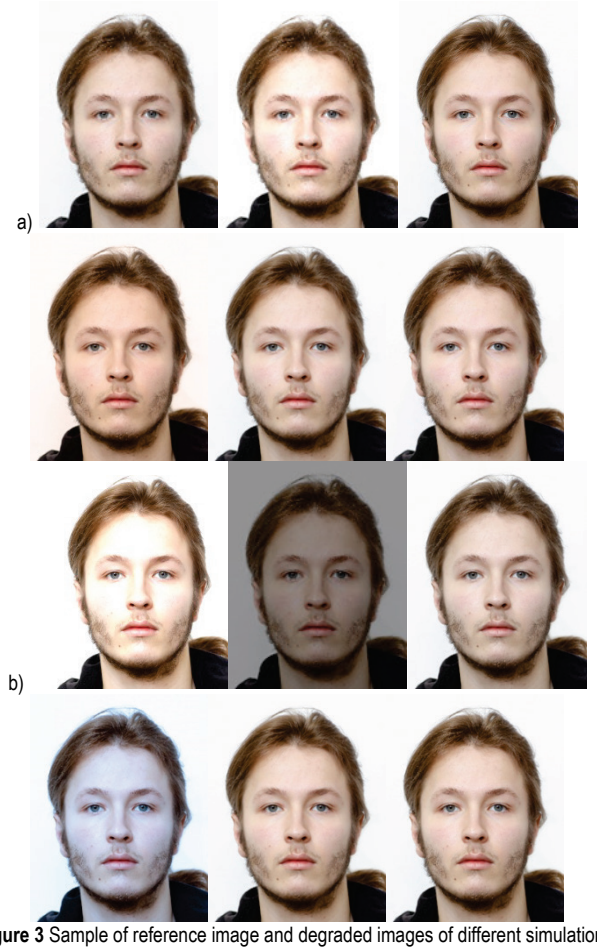


Figure 3 Sample of reference image and degraded images of different simulations: a) completely acceptable b) completely unacceptable

3 REASERSCH RESULTS WITH DISCUSSION

The results of the empirical research based on the application of eye tracking technology are shown in Tab. 1 and Fig. 4.

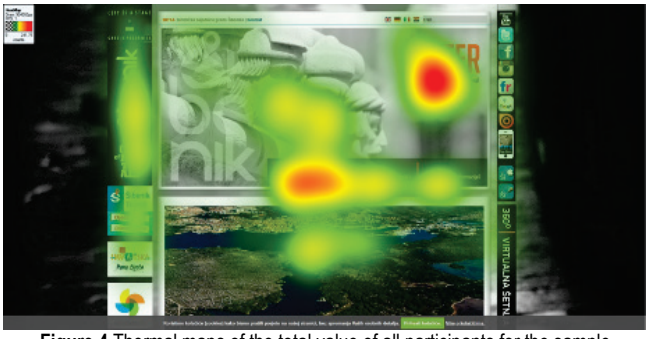


Figure 4 Thermal maps of the total value of all participants for the sample "Šibenik". Source: https://www.sibenik-tourism.hr

Statistical parameters for the variables Time to first fixation, Total duration of fixation, Fixation count and Visit duration grouped according to the observed contents of the sample "Šibenik" are shown in Tab. 1. Time to first fixation shows a wide range of shortest time from only 0.63 s for content C-central photo of face to 4.90 s for content D-logo Hrvatska. The total duration of fixation, the fixation count

and the visit duration is the longest for the content of the C-central photography of the face (Fig. 2).

The results of the experts' estimation of the acceptability of the degradation of the portrait photographic image by simulating the changes of exposure, saturation and applying corrective filters changes are shown in Tabs. 2, 3 and 4.

Table 1 Statistical parameters for the variables Time to first fixation, Total duration of fixation, Fixation count and Visit duration grouped according to the observed contents of the sample "Šibenik". A- social networks; B-text festivals; C-central photography of faces; D-logo HR; E-logo Šibenik; F- navigation; G-photography 2; mean value; SD standard deviation; SE standard error; M-median.

Variables	Statistical parameters	Content						
		A	B	C	D	E	F	G
Time to first fixation	$\bar{X}$	4,61	3,24	0,63	4,90	1,78	1,96	2,19
	SD	2,60	2,33	1,03	2,19	1,95	1,94	2,13
	SE	0,34	0,22	0,08	0,31	0,19	0,17	0,18
	Min.	0,00	0,00	0,00	0,00	0,00	0,00	0,00
	Max.	7,99	7,98	6,06	8,04	7,10	7,98	7,56
	M	5,30	3,33	0,32	5,53	0,76	1,49	1,87
Total duration of fixation	$\bar{X}$	0,59	1,06	2,51	0,36	0,69	1,55	1,33
	SD	0,38	0,75	1,40	0,19	0,54	1,28	1,06
	SE	0,05	0,07	0,12	0,03	0,05	0,11	0,09
	Min.	0,06	0,07	0,25	0,01	0,10	0,06	0,03
	Max.	1,60	3,98	8,05	1,12	2,71	7,20	5,49
	M	0,51	0,87	2,22	0,32	0,52	1,27	1,03
Fixation count	$\bar{X}$	2,07	3,76	8,24	1,21	2,59	5,04	4,42
	SD	1,34	2,33	3,55	0,41	1,71	3,23	3,23
	SE	0,18	0,22	0,29	0,06	0,16	0,28	0,28
	Min.	1,00	1,00	1,00	1,00	1,00	1,00	1,00
	Max.	6,00	14,00	21,00	2,00	8,00	14,00	17,00
	M	2,00	3,00	8,00	1,00	2,00	5,00	3,00
Visit duration	$\bar{X}$	0,55	0,84	1,11	0,35	0,40	0,87	0,70
	SD	0,39	0,60	0,91	0,19	0,31	0,84	0,49
	SE	0,05	0,06	0,07	0,03	0,03	0,07	0,04
	Min.	0,06	0,07	0,24	0,01	0,10	0,06	0,03
	Max.	1,60	4,15	8,05	1,12	2,71	4,61	2,83
	M	0,40	0,70	0,87	0,30	0,30	0,57	0,58

Table 2 Experts' estimation for degradation in exposure

Method	+0,33	–0,33	+0,66	–0,66	+1	–1
M	4	3,2	1,5	2,2	1	1,3
S	4	3,1	1,6	2,3	1	1,2

Table 3 Experts' estimation for degradation in saturation

Method	+5	–5	+10	–10	+15	–15
M	3,8	3,7	3	3	2,3	3
S	3,7	3,6	3	3	2,2	3

Table 4 Experts' estimation for degradation in color temperature

Method	Warm LBA	Warm 81	Warm 85	Cool 80	Cool 82	Cool LBB
M	3,7	3,3	3	2,8	1	1,6
S	3,6	3,1	3	2,7	1	1,7

In the results shown in Tabs. 2, 3 and 4, experts took into account changes in colors and tonal values based on the simultaneous and the memory visual comparison. High consistency of the results of simultaneous and memory comparison confirms the qualitative ability of experts, and high consistency of the results (in the criteria of the color, tone values, saturation and the corrective filters applied) and their acceptability as the expert group. Memory comparison can be considered closer to the real conditions of consumption of the photographic images realized on web pages (and in general) because consumers generally do not directly compare photographic images realized on the different devices and output units. This comparison in the expert group also gives a slightly higher tolerance of color and tone values changes, regardless the degradation method, but generally, the method of visual comparison in the expert group did not significantly affect the estimation of the degraded photographic images.

Tab. 2 shows that experts accept the change of 1/3 of the lens aperture as the limit change, i.e. the degraded tone values and colors are considered acceptable, and larger changes are not. The total exposure increase of 1/3 of the lens aperture is considered completely acceptable, and the decrease of 1/3 of the lens aperture is considered acceptable. Tab. 3 shows that the increase and decrease in saturation within ± 10 experts estimate as acceptable, but the decrease in the saturation for the maximum observed value -15 is estimated as acceptable as well. This can be explained by the specificity of the portrait as the motif often realized in the black-and-white photographic system, and experts estimated the approach to this system as acceptable. Skin color primarily determines the perception of the portrait photographic image, so its proximity to the achromatic point should be taken into account. For other photographic motifs, in terms of saturation, potentially different results can be expected.

The general acceptability of the color temperature increase, i.e. simulation of warm corrective filters, and extremely low acceptability of cold corrective filters (Tab. 4) coincides with the previous research [4,13] which considers the increase of the R channel as more acceptable than increase of the B channel. These results should be taken into account in the calibration of output units, and in defining the light consumption conditions.

Tabs. 5-11 show the L *, a *, b * values of the standard skin colors, achromatic colors, and average colors of the Adobe Camera Raw color table for the color table defined as the original (Tab. 5) and the degraded color tables (Tabs. 6-11). Tabs. 6-11 show the total color differences expressed as ΔE_{00} in the relation to the defined original for the observed colors.

Table 5 L *, a *, b * values for original color table

Color	Phase	L*	a*	b*
Dark skin (DS)	Original	38	14	16
Light skin (LS)	Original	67	17	18
White (W)	Original	96	0	0
Neutral 8	Original	81	0	0
Neutral 6.5	Original	65	0	0
Neutral 5	Original	51	0	0
Neutral 3.5	Original	35	0	0
Black (K)	Original	20	0	0
Average color	Original	56,8	4	4,3

According to previous research results, the limit of ΔE_{00} 6 is defined as the acceptable limit for photographic images in real conditions. The change in skin colors by increasing and decreasing the exposure by 1/3 of the lens aperture can be taken as acceptable (Tabs. 6 and 7). Tabs. 6 and 7 show that the change of the exposure for 1/3 of the lens aperture, the observed colors change is within the limits of acceptability, which coincides with the experts' estimations (Tab. 2). In this case, the simulation of the change in exposure primarily affects the lightness (L-value), affecting the tonal values, which in achromatic colors and colors close

to achromatic colors can be considered as the primer acceptability modulator [4].

Table 6 Color change values by simulating exposure increase

Color	Exposure	L*	a*	b*	ΔE_{00}
Dark skin (DS)	+0,33	38	14	16	3,8196
Light skin (LS)	+0,33	67	17	18	5,4258
White (W)	+0,33	96	0	0	2,3298
Neutral 8	+0,33	81	0	0	5,2605
Neutral 6.5	+0,33	65	0	0	5,4471
Neutral 5	+0,33	51	0	0	3,9022
Neutral 3.5	+0,33	35	0	0	3,3773
Black (K)	+0,33	20	0	0	1,3987
Average color	-	56,8	4	4,3	3,870125
Color	Exposure	L*	a*	b*	ΔE_{00}
Dark skin (DS)	+0,66	47	17	20	8,5764
Light skin (LS)	+0,66	81	20	21	10,5264
White (W)	+0,66	100	0	0	2,3298
Neutral 8	+0,66	97	0	0	10,119
Neutral 6.5	+0,66	80	0	0	10,4582
Neutral 5	+0,66	62	0	0	10,1821
Neutral 3.5	+0,66	43	0	0	6,9393
Black (K)	+0,66	25	0	0	3,5533
Average color	-	66,8	4,6	5,1	7,8355625
Color	Exposure	L*	a*	b*	ΔE_{00}
Dark skin (DS)	+1	52	18	21	13,6244
Light skin (LS)	+1	87	14	20	14,626
White (W)	+1	100	0	0	2,3298
Neutral 8	+1	100	0	0	11,8466
Neutral 6.5	+1	87	0	0	15,0867
Neutral 5	+1	68	0	0	15,0585
Neutral 3.5	+1	47	0	0	10,7057
Black (K)	+1	25	0	0	3,5533
Average color	-	70,6	4	5,1	10,853875

Table 7 Color change values by simulating exposure decrease

Color	Exposure	L*	a*	b*	ΔE_{00}
Dark skin (DS)	-0,33	34	13	15	3,4271
Light skin (LS)	-0,33	61	15	16	5,2054
White (W)	-0,33	88	0	0	4,9187
Neutral 8	-0,33	74	0	0	4,9746
Neutral 6.5	-0,33	60	0	0	5,0659
Neutral 5	-0,33	46	0	0	4,9645
Neutral 3.5	-0,33	31	0	0	3,2087
Black (K)	-0,33	18	0	0	1,3696
Average color	-	51,5	3,5	3,875	4,1418125
Color	Exposure	L*	a*	b*	ΔE_{00}
Dark skin (DS)	-0,66	31	11	14	6,1774
Light skin (LS)	-0,66	55	14	16	10,604
White (W)	-0,66	80	0	0	10,2165
Neutral 8	-0,66	67	0	0	10,3404
Neutral 6.5	-0,66	54	0	0	10,5547
Neutral 5	-0,66	42	0	0	8,7179
Neutral 3.5	-0,66	28	0	0	5,513
Black (K)	-0,66	51	0	0	2,7112
Average color	-	51	3,1	3,6	8,1043875
Color	Exposure	L*	a*	b*	ΔE_{00}
Dark skin (DS)	-1	28	12	12	8,4224
Light skin (LS)	-1	50	13	14	15,5731
White (W)	-1	73	0	0	15,1995
Neutral 8	-1	61	0	0	15,2895
Neutral 6.5	-1	49	0	0	15,5021
Neutral 5	-1	37	0	0	13,0577
Neutral 3.5	-1	25	0	0	7,7353
Black (K)	-1	14	0	0	4,0255
Average color	-	42,1	3,1	3,2	11,8506375

Table 8 Color change values by simulating saturation increase

Color	Saturation	L*	a*	b*	ΔE_{00}
Dark skin (DS)	+5	38	14	17	0,6694
Light skin (LS)	+5	67	18	19	0,6815
White (W)	+5	96	0	0	0
Neutral 8	+5	81	0	0	0
Neutral 6.5	+5	66	0	0	0
Neutral 5	+5	51	0	0	0
Neutral 3.5	+5	35	0	0	0
Black (K)	+5	20	0	0	0
Average color	-	56,8	4	4,5	0,1688625
Color	Saturation	L*	a*	b*	ΔE_{00}
Dark skin (DS)	+10	38	16	18	1,487
Light skin (LS)	+10	67	18	20	1,1113
White (W)	+10	96	0	0	0
Neutral 8	+10	81	0	0	0
Neutral 6.5	+10	66	0	0	0
Neutral 5	+10	51	0	0	0
Neutral 3.5	+10	35	0	0	0
Black (K)	+10	20	0	0	0
Average color	-	56,8	4,3	4,8	0,3247875
Color	Saturation	L*	a*	b*	ΔE_{00}
Dark skin (DS)	+15	38	17	19	2,1822
Light skin (LS)	+15	67	20	21	1,9698
White (W)	+15	96	0	0	0
Neutral 8	+15	81	0	0	0
Neutral 6.5	+15	66	0	0	0
Neutral 5	+15	51	0	0	0
Neutral 3.5	+15	35	0	0	0
Black (K)	+15	20	0	0	0
Average color	-	56,7	4,6	5	0,519

Table 9 Color change values by simulation by saturation decrease

Color	Saturation	L*	a*	b*	ΔE_{00}
Dark skin (DS)	-5	38	14	16	0
Light skin (LS)	-5	67	16	17	0,7092
White (W)	-5	96	0	0	0
Neutral 8	-5	81	0	0	0
Neutral 6.5	-5	66	0	0	0
Neutral 5	-5	51	0	0	0
Neutral 3.5	-5	35	0	0	0
Black (K)	-5	20	0	0	0
Average color	-	56,7	3,8	4,1	0,08865
Color	Saturation	L*	a*	b*	ΔE_{00}
Dark skin (DS)	-10	38	13	15	0,7965
Light skin (LS)	-10	67	15	15	1,8522
White (W)	-10	96	0	0	0
Neutral 8	-10	81	0	0	0
Neutral 6.5	-10	66	0	0	0
Neutral 5	-10	51	0	0	0
Neutral 3.5	-10	35	0	0	0
Black (K)	-10	20	0	0	0
Average color	-	56,7	3,5	3,8	0,3310875
Color	Saturation	L*	a*	b*	ΔE_{00}
Dark skin (DS)	-15	39	12	13	2,1954
Light skin (LS)	-15	67	14	15	2,2198
White (W)	-15	96	0	0	0
Neutral 8	-15	81	0	0	0
Neutral 6.5	-15	66	0	0	0
Neutral 5	-15	51	0	0	0
Neutral 3.5	-15	35	0	0	0
Black (K)	-15	20	0	0	0
Average color	-	56,8	3,25	3,5	0,5519

Table 10 Color change values by simulating a corrective filter

Color	Filter	L*	a*	b*	ΔE_{00}
Dark skin (DS)	WF 81	38	18	22	3,4978
Light skin (LS)	WF 81	67	21	28	5,0751
White (W)	WF 81	97	2	6	5,858
Neutral 8	WF 81	81	10	18	15,2811
Neutral 6.5	WF 81	66	8	15	13,3845
Neutral 5	WF 81	51	7	11	11,3181
Neutral 3.5	WF 81	35	5	9	9,2675
Black (K)	WF 81	20	4	6	7,1239
Average color	-	56,8	9,3	14,3	8,85075
Color	Filter	L*	a*	b*	ΔE_{00}
Dark skin (DS)	WF 85	96	3	6	6,4165
Light skin (LS)	WF 85	81	5	6	7,8959
White (W)	WF 85	96	3	6	6,4165
Neutral 8	WF 85	81	5	6	7,8959
Neutral 6.5	WF 85	66	3	5	5,8421
Neutral 5	WF 85	51	3	4	5,3022
Neutral 3.5	WF 85	35	2	3	3,8729
Black (K)	WF 85	20	1	3	3,1187
Average color	-	56,7	6,5	8,25	4,4541375
Color	Filter	L*	a*	b*	ΔE_{00}
Dark skin (DS)	WF LBA	38	18	19	2,1276
Light skin (LS)	WF LBA	67	21	24	3,2632
White (W)	WF LBA	97	3	5	5,8719
Neutral 8	WF LBA	81	8	12	12,2621
Neutral 6.5	WF LBA	66	7	11	11,3181
Neutral 5	WF LBA	51	6	8	9,4696
Neutral 3.5	WF LBA	35	5	6	7,8959
Black (K)	WF LBA	20	3	3	4,8214
Average color	-	56,9	8,9	11	7,128725

Table 11 Color change values by simulating a corrective filter

Color	Filter	L*	a*	b*	ΔE_{00}
Dark skin (DS)	CF LBB	37	18	0	12,5961
Light skin (LS)	CF LBB	66	23	-4	16,3963
White (W)	CF LBB	98	1	-3	3,3328
Neutral 8	CF LBB	80	13	-20	17,0388
Neutral 6.5	CF LBB	65	11	-17	15,4064
Neutral 5	CF LBB	50	9	-15	13,8787
Neutral 3.5	CF LBB	34	7	-11	11,3475
Black (K)	CF LBB	19	5	-9	9,293
Average color	-	56,1	10,9	-9,9	12,4112
Color	Filter	L*	a*	b*	ΔE_{00}
Dark skin (DS)	CF 82	37	18	0	3,3328
Light skin (LS)	CF 82	66	23	-4	17,0388
White (W)	CF 82	98	1	-3	15,3847
Neutral 8	CF 82	80	13	-20	13,8787
Neutral 6.5	CF 82	66	11	-17	11,3475
Neutral 5	CF 82	50	9	-15	9,293
Neutral 3.5	CF 82	34	7	-11	3,3328
Black (K)	CF 82	19	5	-9	17,0388
Average color	-	56,2	10,8	-9,8	12,358175
Color	Filter	L*	a*	b*	ΔE_{00}
Dark skin (DS)	CF 80	38	17	11	4,9309
Light skin (LS)	CF 80	67	21	11	6,4205
White (W)	CF 80	97	1	-4	3,9418
Neutral 8	CF 80	80	11	-1	12,0538
Neutral 6.5	CF 80	65	8	0	9,4801
Neutral 5	CF 80	50	7	-1	8,5804
Neutral 3.5	CF 80	34	5	-1	6,5165
Black (K)	CF 80	20	3	-2	4,4331
Average color	-	56,4	9,1	1,6	7,04463

Tabs. 8 and 9 show the changes in the observed colors by changing the saturation. Increase and decrease in saturation by the value of 5 was estimated as completely acceptable (Tab. 3). The measured values show the changes that are assessed as visually imperceptible (ΔE_{00} 0.2 or less). It should be emphasized that Tabs. 8 and 9 indicate small overall color differences of degraded photographic images compared to the original by changing the saturation within the observed limits and that the saturation change of ± 15 still gives acceptable differences ($\Delta E_{00} < 3$) even for the consumption by direct comparison, although experts estimated the change in saturation +15 as unacceptable (Tab. 2). This can be explained by the specifics of skin color as the primer modulator of portrait photographic image perception.

Tab. 10 indicates that the simulation of the warm corrective filter WF 85 application changes the standard skin color above the limits of acceptability ($\Delta E_{00} > 6$) but, due to the perception of the warmer skin color as the healthier, experts estimate this degradation as acceptable as well. The application of the cold corrective filters (Tab. 11) changes colors more markedly, i.e. in the observed cases ΔE_{00} changes are larger than with the application of warm corrective filters (Tab. 10). As the acceptable degradation limit for cold corrective filters, only the change by the CF 80 filter can be taken, which was also confirmed as acceptable by the experts' estimation.

Tabs. 12, 13, and 14 show the acceptability of reducing the sharpness of the photographic image — Tab. 12 by expert evaluations, Tab. 13 the ability of line separation by degrading of sharpness simulation, and Tab. 14 by reducing the fineness of JPEG records. Tabs. 13 and 14 show the LW/PH values according to ISO 12233.

Table 12 Degradation by sharpness decreases and fineness of the record change - the expert evaluation

Method	10	20	30	40	50	60	L	M	Max
M	3,8	4	3	2,5	1	1	4	4	4
S	3,7	4	3	2,4	1	1	4	4	4

Table 13 Degradation by sharpness decrease - line separation according to table 12233

Direction	Original	10	20	30	40	50	60
Horizontal	1400	1000	600	300	150	-	-
Vertical	1500	1200	600	300	150	-	-

According to the experts, the degradation of sharpness for the value of 40 is the limit of acceptability, and the value of 50 is unacceptable. According to Tab. 13, this degradation limit gives the line separation ability of 150 LW/PH. Tab. 12 also shows that experts consider all observed degradations by reducing the fineness of JPEG records to be completely acceptable, which is confirmed by the practically unchanged ability of line separation according to ISO 12233 shown in Tab. 14.

Table 14 Degradation by fineness of the record change for Low 1, Medium 5, Height 8, Maximum 12 - line separation according to table 12233

Direction	Original	12	8	5	1
Horizontal	1400	1400	1400	1400	1400
Vertical	1500	1500	1500	1500	1400

4 CONCLUSION

Research analysis confirmed that the Internet is recognized as a place of tourist promotion and that certain

elements affect the quality of the website in terms of information, ease of access to certain content. The selected page is adapted to the use of multiple search engines. They are well connected with social networks, although it has been noticed that the potential of Instagram is not used enough. Multilingualism is well represented, with dominant English. Visual intelligibility is based on the consistent use of the principles of contrast, balance, rhythm, composition and unity. On the symbolic level, the content is most often communicated through color. The perception of the Republic of Croatia based on the research results of this element show that it is still perceived as a destination of the sea and the sun. All analyzed destinations have a pronounced visual element, and what is missing is a complete visual story of the Republic of Croatia, which can be changed following the strategic national guidelines for web promotion. When designing a website, the authors suggest the implementation of a central photography and a larger number of photographic images, logos with the use of color that follows a coherent approach to tourism promotion at the national level. Scientific research based on the eye-tracker analysis indicates the importance of implementing facial photographic image into touristic web page design. Research results proved facial photographic image to be the most important element of entry, based on the results of speed of observation and length of focus on individual content, measuring time to first fixation, total duration of fixation, fixation count and visit duration. The authors suggest the inclusion of facial photographic image as an integral element in the creation of tourist websites. The authors propose the application of the conducted research methods based on deductive sequence for predicting future scientific researches. Based on the scientific research of facial photographic image's technical characteristics, the authors propose certain guidelines regarding the quality control of the display and experience related to the characteristics of color, sharpness, saturation, using simulation and degradation of facial photographic image that can positively reflect on tourism development.

Based on the study of the acceptability of the degradation of a portrait photographic image that corresponds to the technical website's photographic images characteristics, it is concluded that the degradation of tones and colors due to simulation of exposure change 1/3 of the lens aperture is in the limit of acceptability. This is confirmed by expert estimation, determination of the total color difference ΔE_{00} and the changes in height (i.e. L value) observing the skin color as the dominant in the portrait photographic image analysis. The change in saturation within limits of ± 10 can be defined as completely acceptable saturation degradation, based on the experts' estimation and the determination of the total color difference. The portrait is the photographic motif in which the perception of the photographic image primarily depends on the reproduction of skin color. Near the achromatic point, experts' estimation confirms even greater tolerance in saturation decrease, but this conclusion cannot be considered as universal for other photographic motifs of websites in the function of tourism promotion and development.

Expert estimation and determination of the total color difference indicate a higher tolerance for the simulation of changes by warm than cold corrective filter application, which coincides with previous research of portrait photographic images indicating the higher tolerance of increasing the value of R, than B recording channels. This conclusion, apart from being an indicator of degradation tolerance, can also be used in the output unit calibration and light consumption conditions.

Regarding the tolerance of degradation of the portrait photographic image used for the realization of web pages in the function of promotion and development of tourism, the limit of acceptability in decrease in sharpness the value of 40 is defined, while for the fully acceptable degradation the limit of value 20 can be defined. It means reducing the ability to separate lines from 1400 (horizontal), 1500 (vertical) LW / PH for original to 600 (horizontal) 600 (vertical) LW / PH for value of degradation 20 and 150 (horizontal) 150 (vertical) for value of degradation 40. Reducing the fineness of JPEG format recording did not affect the acceptability of the sharpness of the observed portrait photographic images, which can be used in optimizing records for the realization of websites in the function of tourism promotion and development.

5 REFERENCES

[1] Ministarstvo turizma Republike Hrvatske – Strategija razvoja turizma. https://mint.gov.hr/strategija-razvoja-turizma-11411/11411 (Accessed: 11.02.2021) (in Croatian)

[2] Mikota, M. (2016). Fotografija – Tehnički i semantičko-sintaktički izazovi medija u novom okruženju. *Tiskarstvo & Dizajn 2016,* 175-178. (in Croatian)

[3] Periša, M., Mrvac, N. & Mikota, M. (2015). The visual grammar of photographic images produced by media convergence. *Communication Management Forum Proceedings Zagreb, Edward Bernays,* 647-667.

[4] Mikota, M., Brozović, M., & Pavlović, I. (2008). Kvalitetafotografske prezentacije modnih noviteta u medijima vanjskog oglašavanja. *Tekstil: časopis za tekstilnu tehnologiju konfekciju, 57*(9), 457-464. (in Croatian)

[5] Ahtik, J. & Starešinič, M. (2017). Eye movement analysis of image quality parameters compared to subjective image quality assessment. *Tehnički vjesnik, 24*(6), 1833-1839. https://doi.org/10.17559/TV-20161213185321

[6] Mohammadi, P., Ebrahimi-Moghadam, A., & Shirani S. (2014). Subjective and objective quality assessment of image. *Majlesi Journal of Electrical Engineering, 9*(1), 55-83.

[7] Pavlović, I., Mikota, M., & Mrvac, N. (2009). Exposure Correction in Digital Portrait Photography Taken with the Nitraphot Lighting. *DAAAM Symposium "Inteligent Manifacturing & Automation: Focus on Theory, Practice and Education". DAAAM International,* 1449-1450.

[8] Pilarczyk, J., & Kuniecki, M. (2014). Emotional content of an image attracts attention more than visually salient features in various signal-to-noise ratio conditions. *Journal of Vision, 14*(12), 1-19. https://doi.org/10.1167/14.12.4

[9] Ha, J., Byon, Y.-J., Cho, C.-S., & Seong, P. (2018). Eye-Tracking Studies Based on Attentional-Resource Effectiveness and Insights into Future Research. *Nuclear Technology*, 202, 1-10. https://doi.org/10.1080/00295450.2018.1428003

[10] Erhu, Z., Jia, Y., Yajun, C., & Yang, Y., (2010). A study of image color quality evaluation based on S-CIELAB. *The 3rd International Congress on Image and Signal Processing*, 3. https://doi.org/10.1109/CISP.2010.5646866
[11] Sharma, G., Wu, W., & Dalal, E., N. (2005). The CIEDE2000 color difference formula: implementation notes, supplementary test dana and mathematical observations. *Journal Color Research & Application, 30*(1) 21-30. https://doi.org/10.1002/col.20070
[12] ISO 3664: 2009 Graphic technology and photography — Viewing conditions https://www.iso.org/standard/43234.html
[13] Mikota, M., Matijević, M., & Pavlović, I. (2016). Colour reproduction analysis of portrait photography in cross-media system: image on the computer monitor-electrophotographic printing. *Imaging Science Journal, 64*(6), 299-304. https://doi.org/10.1080/13682199.2016.1184875

Authors' contacts:

Petra Ptiček
University of Zagreb, Faculty of Graphic Arts,
Getaldićeva 2,
10000 Zagreb, Croatia
E-mail: pticekpetra@gmail.com

Ivana Žganjar, PhD,
University of Zagreb, Faculty of Graphic Arts,
Getaldićeva 2,
10000 Zagreb, Croatia
E-mail: ivana.zganjar@grf.unizg.hr

Miroslav Mikota, PhD, Assistant Professor
(Corresponding author)
University of Zagreb, Faculty of Graphic Arts,
Getaldićeva 2,
10000 Zagreb, Croatia
E-mail: miroslav.mikota@grf.unizg.hr

Mile Matijević, PhD, Assistant Professor
University of Zagreb, Faculty of Graphic Arts,
Getaldićeva 2,
10000 Zagreb, Croatia
E-mail: mile.matijevic@grf.unizg.hr

ISSN 1846-6168 (Print), ISSN 1848-5588 (Online)
https://doi.org/10.31803/tg-20210517001244

Original scientific paper

Exploring Successful Small Urban Spaces' Criteria with Emphasis on Cultural Context

Parvin Partovi, Kebria Sedaghat Rostami*, Amir Shakibamanesh

Abstract: In the crowded cities of the present age, public spaces can provide a quiet area away from the hustle and bustle of the city that citizens can interact with by incorporating utility features and meeting human needs and Relax there. Small urban spaces are among the most important and effective urban spaces to achieve this goal. Because these spaces due to their small size and lower costs (compared to larger spaces) for construction can be created in large numbers and distributed throughout the city. In this way, citizens will be able to reach a public urban space on foot in a short time. If these spaces are well designed, they can encourage people to stay in and interact with each other. It is not difficult to identify and experience high-quality successful places, but identifying the reasons for their success is difficult and even more difficult, understanding if similar spaces in other places can be considered successful. This question is important because public space with deep social content is considered a cultural product. Public space is the product of the historical and socio-cultural forces of society. Therefore, one of the most important issues that should be considered in the study of public spaces and the reasons for their success is the cultural context. In Iranian cities that have been influenced by the values and principles of Islam, recognizing Islamic principles and their role in shaping public spaces can lead us to desirable results. The purpose of this article is to develop a conceptual model of successful small urban spaces with an emphasis on cultural issues, especially in Iranian-Islamic cities. In this regard, the effective criteria for the success of urban spaces in general and small urban spaces in particular in the two categories of Western countries and Iranian Islamic cities were examined and then, taking into account the criteria derived from cultural theorists, the conceptual model of research with 38 sub-criteria is provided.

Keywords: contextualism; culture; successful space; urban space

1 INTRODUCTION

Different scales can be identified for urban spaces due to many issues, such as function, size, capacity, and their location in the city, especially concerning urban divisions and hierarchies [1]. Since each person has different needs, one space cannot meet all the needs of all users. Therefore, a city must offer different types of public spaces [2]. Public spaces have various scales from small spaces city.

Small public spaces include features such as small size, large accessibility, and many facilities. These spaces provide attractive views and easy access. Unlike large urban parks and squares or other regional public spaces, small public spaces mainly consist of small squares and small parks around blocks and open spaces between buildings. In terms of spatial pattern, small public spaces (as opposed to the linear space of streets or alleys) are primarily blocks or dots. In terms of space size, the criteria vary slightly between countries and regions [3].

Small scale-spaces are very important. Rob Carrier also believes that traditional small-scale urban spaces have proved to be a place of communication for thousands of years; Spaces with a human scale that can be easily walked. Numerous activities take place in these spaces and group activities including sports and games, chess, and card games are prominent in small and medium public squares [4]. People need small spaces because they provide a place to relax and, most importantly, spontaneous social interactions. Social interaction is the mainstay of social capital. Places with good social capital are sustainable and successful. Building social capital is not very easy, but it is easy to create spaces that can shape social capital. Small urban spaces are some of the best spaces for this aim. In addition, the most essential need in most cities is spaces that everyone can access. Ideally, no one should be more than 1.4 miles (about 2250 meters) away from a small space [5].

1.1 Small Public Space Theorists

The issue of the scale and size of public space has always been a thoroughly studied and analyzed subject; for example, by people like Jacobs (1961), Seymour (1969), Whyte (1980 and 1988), Cooper Marcus and Francis (1998) and Gehl (1989-2011). Jane Jacobs has conducted a comprehensive social analysis of small pedestrian spaces, saying that pedestrians are small but penetrate the entire city and often go beyond a narrow corridor and act as small public squares [6]. Seymour (1969) was the first theorist that used the term 'small urban space' to change the prevailing view of small urban parks. He mostly referred to small urban spaces as urban parks and children's playgrounds. Seymour points out that to maintain our cities and make them habitable; we need positive programs that provide beauty, fun, and enjoyment to the inhabitants of our cities. Meanwhile, the proper use of small urban spaces can significantly contribute to this process.

William Whyte carried one of the most extensive projects to investigate the causes of the success of small urban spaces out. Whyte believes that people use spaces in which they feel comfortable and can easily move around. He believes that the multiplicity of small spaces is enormous and not only the people who use it enjoy it, but all the passers-by and even all the residents of the city who are aware of its existence. In a city, such places that are built at low costs are economical. It can be said that Whyte believed that people are attracted to other people [7]. According to Whyte, the presence of a large number of women, the existence of the right to choose between sun and shadow, large seating space, the use of water sound and visual beauty, the absence of harmful people, and the phenomenon of triangulation make small spaces successful. A great change was made after Whyte's innovative research. Zukin believes that Whyte was

an inspiration to many urban designers and planners and his research changed the way we study cities [8].

Seeking a more active public life in the harsh climate of Scandinavian cities, Jan Gehl used Whyte's method to study Danish urban spaces. He prefers small-scale spaces and says that in narrow streets and small spaces we can see the buildings, details, and people around us at a short distance. On the contrary, a large scale leads to confusion of people [9]. Cooper Marcus and Francis (1976) conducted another similar study. During their research, they have identified different types of public spaces (six types), three of which are small spaces namely street square, which is a part of public open space that is very close to the sidewalk, is open, and has a close connection with the street. Such spaces are usually used for short periods to sit, wait and watch; Common courtyard (collective space) is part of a building complex and its main use is the definition of entrance space. It is usually privately owned but publicly available; Passage/related to public transportation (temporary stop space) which is a square-like space that has been created for easy access to the entrance and exit of crowded public transportation terminals. Although the predominant activity is traffic, terminal users sometimes attract traveling vendors and viewers.

2 URBAN SPACE DESIGN CONCERNING CULTURAL CONTEXT

One of the important cases in postmodern urban planning is the organization of a suitable space for the social and cultural context of the city [10]. Culture in its simple definition is the discipline that connects people with the outside world [11]. In general, it is believed that the physical product of each society reflects its culture. The most important physical product of a society is the body and urban architecture that society creates for itself to grow and transfer culture from one generation to another [12]. Contextualists believe that the analysis of a physical phenomenon is possible when we know how it is perceived in that culture. Therefore, the context-oriented urban planner should be able to understand the characteristics of a place and make it a part of his design process [13].

The cultural system and social relations are interconnected. On the one hand, culture is the product of social relations and the establishment and continuation of social relations strengthen values and norms or culture. On the other hand, culture determines the conditions and manner of formation of social relations. Since the main function of public space is to prepare a context for the presence of people, a social and cultural relationship takes place in space [14]. Space becomes a place where cultural and physical characteristics are combined with the emotional perceptions and functional needs of individuals. This is why the revitalization of places without considering cultural features leads to the no-place [15].

Meanwhile, the task of urban planners is to create a place that provides the best fit between the cultural and physical contexts and the needs and expectations of users [14]. In the next step, the design of the space is important. Design should provide appropriate opportunities for the expression of culture, and users with different social groups and different cultures of users from the culture of designers should be considered.

2.1 Culture and Urban Space Theorists

Paying attention to culture in recognizing and explaining the city is not a new issue. Many theorists have paid attention to the importance of the cultural dimensions of the city since the beginning of the emergence of industrial cities in the nineteenth century [16]. John Ruskin (1818-1900) is undoubtedly one of the most influential thinkers and critics of the nineteenth century, whose ideas greatly influenced early twentieth-century artists. Ruskin greatly influenced his disciple William Morris. William Morris Davis (1896-1834) does not assent to the uniformity of urban spaces. The views and thoughts of Ruskin and Morris were the results of a comparison between the past and the present. Another thinker in this field is George Simmel (1918-1858). He was the first researcher to take the biological experience of modern urban culture seriously. He claims that the life and culture of those who live in metropolitan areas have been formed mainly through people's reactions to a set of intense stimuli [17]. His attention to the characteristics of life in metropolises influenced theorists such as Walter Benjamin (1892-1940). Benjamin was interested in the interrelationships of the city as a meaningful space of several layers. Like Simmel, he considered the city and the architecture of the city as the main component of modernity [18].

Roland Barthes (1980-1915) is also a theorist whose writings have greatly influenced cultural studies. His attitude towards culture is from the perspective of the meaning-making process. In addition, among thinkers interested in culture and the city, Claude Levi Strauss (1908-2009) is known for introducing structuralism attitudes and methods into anthropology. He sees culture as a set of symbolic systems, all of which he believes aim to express aspects of physical reality and social reality. Strauss believes that to understand any culture, its underlying structure must be understood [19].

Edward T. Hall (1914-12009) is also an anthropologist who is interested in intercultural studies. In his view, culture is the information and methods shared about coding information and saving and retrieving it [20]. His ideas on various types of urban spaces are very valuable. In addition to Hall, Lewis Mumford (1898-1990) is one of the culturists who have valuable theories about the city. He distinguishes the city in two ways: one is the physical means including the fixed body, the stable housing, and permanent installations, and the other is the non-physical means including the division of social labor which guarantees not only economic life but also cultural processes [21]. Sharon Zukin (1946-present), like Mumford, has dealt with the relationship between the city and culture [22]. Finally, we can refer to Amos Rapaport (1921-present) who has different theories about space that emphasize the cultural dimension. He believes that the cultural context is very important because it

describes the events [23]. Tab. 1 shows the views of these theorists.

Table 1 Theorists' views on culture, city, and urban space

Theorist	Viewpoint
John Ruskin	Encouraging honesty in architecture (building materials and methods); Culturally desirable housing is housing in which the houses are beautiful and with appropriate differences in the personality and occupations of their inhabitants; Pro-diversity and anti-repetition (and network grid); Architecture is an art that all people should learn from it because everyone benefits from it; If buildings are built sustainably, this architecture will be passed on to future generations; The proposed use of ancient buildings and textures should be in the direction of historical continuity.
William Moris Davis	Good work is the expression of a complete culture; Public art (sharing many different minds and natures) is valuable; Believes in the correlation between culture and life in a modern way in the field of architecture; People should be involved in creating their living space.
George Simmel	The life and culture of people in metropolitans are mainly formed through people's reactions to a set of intense stimuli; Culture is a shaped mentality that emerges by human beings through the content of human life and interaction; The task of sociology is to describe how individuals come together, the formation of groups, and their interrelationships; Increasing the size of human groups has consequences; Space is not just a physical thing, but a kind of social construction; Establishing a social face at a focal point or around a specific location; Socialization and social interaction fill the space.
Walter Benjamin	Emphasis on historical-cultural spaces as layers of cultural spaces (meaningful in the city); Emphasis on wandering, personal experience, and space exploration; Emphasis on memories and experiences from communication and social interaction and activities; Buildings, spaces, and monuments are both responsive to and reflective of patterns of social activity; The characteristics of urban space are the result of the relationship between buildings and history, culture and activities; Each urban space belongs to a specific place and time and is not repeatable.
Roland Barthes	Considering culture from the perspective of the semantic process; Believing in public arenas and contexts of public cultural spaces; Emphasis on communication, wandering and personal experience and discovering the features of space.
Claude Levi Strauss	Culture is a set of symbolic systems that aim to express aspects of physical and social reality; To understand any culture, one must construct its underpinnings; What makes a human being is not nature but the cultural dimension; In each society, different cultural phenomena are reflected and follow a single structural core.
Edward Hall	Culture is the information and methods shared about the encryption, storage, and retrieval of information; Culture defines communication, just as communication defines culture; Structures provide the context, something that makes communication possible; Cultures generalize different forms of behavior; The study of any space, depending on the normative context and current behavioral events in space, requires a special approach.
Louis Mumford	Emphasizing on historical-cultural spaces; In urban planning, all cultural and historical dimensions are considered; Believing in that social relations are manifested in the form of cultural rituals and ceremonies; Urban space can lead to the growth of potential human forces and give a human face to civilization and culture; Emphasizing on face-to-face and mobility relationships; Urban space is a structure that considers human goals in terms of function and design.
Sharon Zukin	Emphasizing on the architectural body to preserve culture and therefore on local cultural heritage; culture is a tool for controlling cities; Culture is the source of memories, ideas, and belongings of individuals; Believing in everyday life and interaction and experience and cultural exchanges in unpredictable spaces; Public management and open access are two basic principles in public spaces; Culture is the main factor in shaping space.
Amos Rapoport	Culture defines human traits with deep evolutionary roots; Urban space represents culture; Differences in bodies are due to differences in cultures; Socio-cultural realm is the main factor in the formation of space; Emphasizing on designing spaces following the context and culture of society; Cultural differences are effective in organizing the time and rhythm of human activities; Pointing to the difference between urban planners and people in defining environmental quality.

3 THE EFFECTIVE FACTORS IN THE SUCCESS OF URBAN PUBLIC SPACES

In this section, the effective factors in the success of urban public spaces with an emphasis on small urban spaces are proposed. Successful outdoor space has an important effect on people's feelings. Design based on the needs and desires of users is necessary. Since the definition of human needs is different in various cultures and due to the deep cultural differences between Western countries and Iran, there is no doubt that the characteristics of public spaces in these two cultures are different from each other. Of course, similar criteria can be found, but due to differences in the historical, cultural, and spiritual values of countries, it is necessary to examine the characteristics of the success of public spaces separately from Western countries and Islamic Iranian cities.

From the perspective of perception in Western countries, readability is an important factor in the design of urban spaces. Therefore, it is necessary to pay attention to the design of micro-spaces, human scale, space size, and appropriate spatial scale. On the other hand, security is one of the most important factors to attract people to the public space at any time of the day [24]. In this regard, Cremona believes that the presence of women can be a measurement of security. From the point of view of Iranian researchers, readability is also important due to the four factors of space size, integration (existence of coherence in the field space, avoiding excessive fragmentation of space, and the possibility of creating a mental image of the whole space), enclosure and spatial determination (Determining the borders of urban squares), and giving meaning to space [25]. Security is another important factor. The existence of areas and equipment required by different age or social groups and the existence of spontaneous or organized activities to attract and retain citizens are other important issues that allow the presence of individuals [26].

About small urban spaces in particular, in Western sources, factors such as legibility, visibility for pedestrians, and functional accessibility have been mentioned. Whyte also considers the high presence of women and the absence of homeless people and addicts to be effective in the success

of space [6]. In Iranian sources, in addition to referring to these two factors, it is stated that the boundaries of the squares should be clear and understandable to the people inside it in a way that induces the feeling of presence in space [11, 25].

Besides, from the social dimension, several factors affect the success of the space. The formation of social interactions, vitality, and attracting people are the most important features of social space [4]. A successful place is a place that is more alive and active, and the diversity of space users, activities and relationships, and social activities can be seen in it [27].

In Iranian-Islamic cities, the first and most important factor in the success of public space in terms of social dimension is sociability. The possibility of the presence of different individuals and social groups and meeting the needs of all individuals, including material, psychological, and spiritual needs are important criteria for the sociality of the space. Meanwhile, reminding, gentleness with the senses through pleasure, respecting human beings in buildings and behaviors and against the law [28], and interacting with all people are among the characteristics that lead to the spiritual growth of individuals. In addition, space should be lively and provide the possibility of staying or relaxing [25]. One of the qualities that affect the creation of vitality is diversity. We must increase the diversity in the function, activities, times of using the space, and groups of space users [25]. Moreover, vitality in the urban space must be met by criteria such as the desired urban form, preservation of cultural identity and historical continuity; Adjust the space according to the behavioral pattern of people; Providing facilities for happiness and leisure; Provide suitable places for both social and economic activities [29].

In addition, the design of small urban spaces emphasizes intimacy and human connection among space visitors [30]. Moreover, the possibility of social life versus private life and a sense of closeness to the place is essential in the acceptance of space by people and its success as the result [6]. In Iranian cities, local squares as a kind of small urban space bring peace to their users. In addition to tranquility, intimacy and the possibility of dominating the space are other important features of local squares and all residents of the neighborhood should feel a sense of belonging to the local square [11].

In terms of function and accessibility, Western sources state that the position of public space in the spatial hierarchy shows how much space is used. As far as the amount of space use is related to its location, two effective factors can be mentioned: its location concerning the surrounding environment and neighborhoods and how to access space. Space should have strong connections with the surrounding areas and provide easy and unobstructed access for all people. Whyte (1988/1980) also emphasizes the importance of paying attention to street communication due to the inviting perspective (open and transparent street communication and appropriate entrance design). In addition, successful spaces are visible to users, have a suitable entrance and access to public transport, and provide enough parking lots. Another important design priority in public spaces is the safety factor that directly affects the use of space. Proper organization of pedestrian and bicycle paths and protection against accidents lead to a sense of safety in public space [31].

The functional dimension also includes how the site is used (uses and activities). Successful open spaces are those that meet the needs of society and provide the context for economic, social, and cultural activities [33]. In addition, between different parts of a space, the design and use of public space can be done according to the center and edge. Edges are preferred for both sitting and standing by people, and the presence of elements and focal points also attracts more people [34]. Activities also play an important role in defining public urban space. Containing mixed activities is the key to successful urban spaces [33]. In this regard, Whyte believes that the elements should be located in a way that greatly increases the possibility of activity around them [6]. Diverse activities in space can take the form of active engagement (such as running and being able to explore the environment) or passive engagement (such as looking at people and the public arts) [35]. In addition, having a comfortable space and providing user comfort is a key factor for its success. Feeling comfortable includes various factors such as providing the necessary facilities for people, availability of sufficient and comfortable place to sit, feeling of safety and security, and cleanliness. Mental comfort can be a prerequisite for comfort. Relaxation and release of physical and psychological pressures lead to comfort in public spaces. The first functional factor influencing the success of Iranian-Islamic spaces is providing easy and unimpeded physical access for everyone. Another important factor is visibility and visual access. Providing safety through traffic control and connecting to surrounding areas are also among the other effective factors in this field. In this regard, special emphasis is on providing access for pedestrians and access to public transportation [36]. Another very effective factor is the space function and activities. By defining multiple functions, traditional Iranian squares have induced values and controlled the behavior of users, and have helped identify and increase residents belonging to space [37]. These spaces must be creative in creating different functions and meeting the needs of different age or social groups [28] and should be able to provide both social and economic activities [25]. In addition, meeting the needs of play and entertainment and the existence of spontaneous or organized activities to attract people have special importance in achieving a successful public space [26].

Functional factors also play an important role in the efficiency of small urban spaces. Factors such as visibility, maximum physical accessibility [38], proximity and ease of access, location near sidewalks and in connection with the street [6], visual communication with the surrounding network, defining the square entrance [7, 24], providing parking and managing motorcycle parking [3] are influential. On the other hand, diversity in the configuration of spaces, the presence of planned steps and activity edges and attractive focal elements, and the variety and comfort of sitting areas lead to the presence of more people in the space [7]. Successful small space provides functions responding to the needs of the surrounding population and provides the

ability to adapt to a wide range of different functions [38]. Mixed-uses ensure the continued use of public squares throughout the day [38]. The function of the surrounding buildings also has an important role in the dynamics of the space. Moreover, proximity to natural factors, the presence of trees and other plants, the use of adequate sun and wind, and playing with light and shade help to improve the efficiency of small public spaces [6]. In addition, to promote a sense of safety, it is important to ensure that views from inside of the park are not completely closed [30]. In this regard, some cases have been mentioned in Persian sources too. Pakzad considers successful local squares as quiet and not too crowded in which residents' supervision is evident and activities have a local scale. Besides, all people should have quick and easy access to space without movement barriers, car movements should be minimized and disturbing activities with loud noises should not be established [11]. Providing appropriate equipment and furniture in such spaces is important too and there should be facilities to sit in the sun or shade [25].

From a visual landscape point, from Sitte to Moughtin, beauty and originality have been identified as important factors for the success of public areas [7]. Among these, the most important factors that play a role in the beauty and innovation of public spaces are attractive buildings and landscapes, beautiful architecture of the surrounding area, enclosure, proper proportions, appropriate and varied paving, proper landscape arrangement, designing due to topography, designing beautiful furniture, using color and light in space, the difference in level, and visual complexity and diversity [7, 24]. The presence of aesthetic elements also affects enjoying of public space. Appropriate scale, aesthetic quality, and rich emotional experiences are effective in the sense of pleasure [32]. Considering aesthetic factors is the most important factor in Iranian-Islamic urban spaces too. This element includes factors related to beauty and visual attraction such as spatial diversity, proper body, proper flooring, beautiful and desirable landscapes, and visual [18]. In Islamic texts beauty, respect for the human being, creativity and perfectionism and modernity, and paying attention to meaning [28].

Successful small squares also tend to create visual beauty. Therefore, it is suggested that the width and length of the site be appropriate [30]; Of course, a strong sense of enclosure is not necessary for a small successful public space. It is also necessary to pay attention to historical, cultural, and geographical contexts, legibility of the environment, and increasing diversity and avoiding repetition in place [38]. In Iranian-Islamic cities, the small urban space is physically geometrically specific and should be stress-free in the physical elements [25]. In addition, space should have a proper enclosure and a human scale. In addition, entrances should be defined, not inviting; Of course, space should be attractive for residents [18].

From an environmental point of view, every public space should have a comfort zone in different weather conditions. The main factors that affect a person's outdoor comfort are temperature, sunshine, humidity, and wind. People are looking for places that are safe from these factors; Therefore, these issues should be considered when designing the space and locating the sitting spaces. In addition, there should be plant diversity, attention to the height and materials of the surrounding buildings and the orientation of the field for proper lighting, using the element of water, and the protection of people from pollution [6].

In Iranian texts, the existence of environmental comfort and enjoyment of climatic conditions is mentioned as a factor in the success of urban spaces and it is stated that the fields should benefit from light, sun, shadow, and the sound of the wind among the leaves. In addition, preserving the environment due to Islamic instructions, peaceful coexistence with nature, use of natural elements and water [26] are very important in Islamic cities.

In small urban spaces, Whyte believes that sun (especially in winter), wind, water (to stimulate the senses through sound, seeing, and feeling), and trees (due to the creation of shade and natural environment) contribute to the success of space [7]. Regarding the importance of natural elements in Iranian-Islamic cities, it is also stated that light, sun, shadow, and the sound of wind among the leaves should be considered in the squares [25].

In the time dimension, using space at different hours, days and seasons have a great impact on its success [32]. In this regard, Montgomery emphasizes the existence of active activities in the evening and night. Rapaport raises the issue that cultural differences are effective in organizing the time of activities and consequently the desirability of urban space [23]. In Iranian-Islamic cities, characteristics such as maintaining historical continuity, variety in times of using space, and special function in specific or permanent times can be expressed. Flexibility is important in the role, meaning, and function of urban squares, and the square stabilizes its character over time. Different activities and actions also change easily based on needs, time, etc. [25]. Therefore, accompanying time and history and respecting cultural characteristics are valuable principles in the success of Iranian-Islamic public spaces [28]. Time-related factors have not been specifically addressed concerning the success of small urban spaces. This is because the importance of the variables of this dimension is the same in all scales related to space and all types of spaces reflect change over time.

From the management dimension perspective, it can be said that proper management of spaces leads to improving life, work, and leisure experiences. In this regard, long-term planning, short-term measures, respecting mutual rights of space and users, proper management, the absence of barriers to bureaucracy and encouraging local community participation in place management, management coordination to maintain space and create a sense of security and safety, the existence of regulations for the use of space, flexibility in decision-making at all stages, and the existence of dynamic programs are important [7]. In contrast, lack of investment and lack of coordination between activities and stakeholders can lead to reducing quality in public spaces. In addition to the mentioned factors, urban management should maintain space. High-quality maintenance and cleaning the space make it pleasant to the public [39].

In Iranian-Islamic cities, one of the most important factors that help the space to achieve success is managerial factors. Urban space management must perform its duties well in all stages, including planning, implementation, organization, policy-making, and control and supervision [40]. In this regard, space is obliged to respect the rights of city residents and the rights of nature, there should be coordination between different management departments and between management institutions and city residents, proper management should be done in all sectors and there should be space monitoring. Also, in addition to the participation of groups who benefit from space and local management, continuous control and management, unified and centralized management along with paying attention to the council structure of management [28].

Concerning the qualities of the managerial dimension, there is less content that is specifically dedicated to successful small urban spaces. This is because space management to maintain it in all spaces requires managerial cohesion and participation of individuals. In this regard, Pakzad [18] emphasizes the role of local people in the management and monitoring of space and believes that successful local squares are spaces where residents' control is evident.

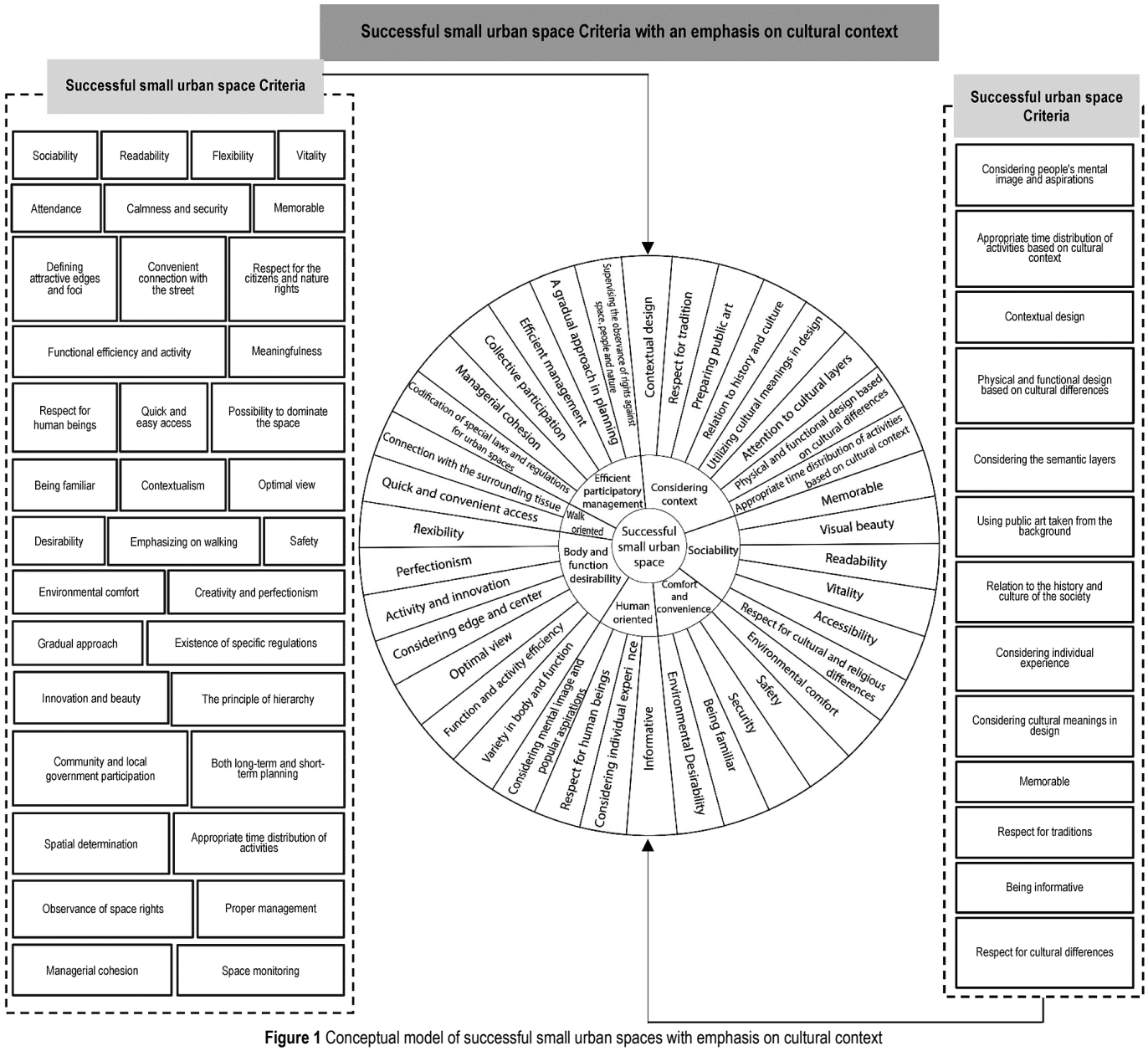


Figure 1 Conceptual model of successful small urban spaces with emphasis on cultural context

4 CONCLUSION

To summarizing the mentioned issues, the factors affecting the success of public spaces in general and small urban spaces, in particular, were combined in two categories of western countries and Iranian-Islamic cities, and those variables of public spaces. In general, they were used that were in line with the characteristics of small urban spaces and

with Iranian Islamic culture, and inconsistent factors were removed. Finally, the conceptual model of the research is formulated as described in Fig. 1. In the right part of this model, the criteria of successful urban space are presented based on what was studied in the cultural context section. In this column, the researcher has developed criteria that are taken from the cultural context of each society and helps to consider cultural differences in the final model. On the left side of the model, the criteria for successful small urban spaces, which are presented in Fig. 1, are given. In the middle part of the model, the criteria of this research are stated. There are seven criteria: contextualism, sociability, comfort, human-centeredness, physical and functional desirability, pedestrianism, and efficient participatory management, each of which has sub-criteria - 38 sub-criteria are provided.

5 REFERENCES

[1] Naghizadeh, M. (2016). *Analysis and design of urban space (principles, definitions, criteria, and methods)*. Tehran: University Jihad Publications.

[2] Efroymson, D., Ha, T. T. K. T., & Ha, P. T. (2009). *Public Spaces: How They Humanize Cities*. Dhaka: HealthBridge, WBB Trust.

[3] Wang, L. & Rongling, L. (2019). Study on the association mechanism between small public spaces and affective responses in the 'human-scale form' perspective-take Tianjin Wudadao Area as an example. *International conference of city and territory in the globalization age*.

[4] Nguyen, N. M. (2017). Towards the Making of User Friendly Public Space in China: An Investigation of the Use and Spatial Patterns of Newly Developed Small and Medium-Sized Urban Public Squares in Guangzhou and Shenzhen. *PhD Thesis*, Victoria University of Wellington. http://hdl.handle.net/10063/5654

[5] Shafer, S. & Jacob, J. (2006). Urban Parks: The Value of Small Urban Parks, Plazas, and Other Outdoor Spaces. https://oaktrust.library.tamu.edu/bitstream/handle/1969.1/87453/pdf_2399.pdf?sequence=1&isAllowed=y

[6] Christoffersen, A. (2010). *The space between: Small-scale design for urban revitalization*. The University of Georgia. Athens, GA.

[7] Whyte, W. H. (1988). The Design of Spaces (An article taken from the author's book *"The city: Rediscovering the center"*). University of Pennsylvania Press.

[8] Zukin, S. (2010). *Naked City: The Death and Life of Authentic Urban Places*. New York: Oxford University Press. https://doi.org/10.1093/oso/9780195382853.001.0001

[9] Gehl, J. (2013). *Human city*. Translation: Ghaffari, A., and Ghaffari, L. Tehran: Royal Architect Science Publications.

[10] Tonekaboni, B., Shahabian, P., & Modiri, A. (2017). Recognition and analysis of socio-cultural changes and developments in public spaces of Tehran. *Cultural Research Society Journal, 8*(4), 133-158.

[11] Pakzad, J. (2006). *Theoretical foundations and urban design process*. Tehran: Samin Publishing.

[12] Isazadeh, K. (2017). Analyzing cognition of culture effect on body and design of cities with emphasis on cultural theories of design of biological complexes. *Journal of Urban Management, 46*, 71-96.

[13] Majedi, H. & Saeedeh Zarabadi, Z. (2010). Marked city as a context-oriented city. *Journal of Cultural Research, 3*(3), 1-21. https://doi.org/10.1016/j.ccs.2010.04.002

[14] Talebi, J. (2004). Social relations in urban spaces. *Journal of Social Science, 24*, 161-180.

[15] Ujang, N. & Zakariya, Kh. (2015). The notion of place, place-making, and identity in urban regeneration. *Preceding social and behavioral sciences*, (170), 709-717. https://doi.org/10.1016/j.sbspro.2015.01.073

[16] Fazeli, N. A. (2020). *Metropolis and culture; Anthropological researches on urban research, culture, and urban politics*. Tehran: Farhameh Publications.

[17] Stevenson, D. (2009). *Cities and urban cultures*. Translation: Panahi, R. & Poorahmad, A. Tehran: Publications of Urban Planning and Architecture Research and Publications Center.

[18] Smith, F. (2019). *An Introduction to Cultural Theory*. Translated by Pouyan, H. Sixth edition. Tehran: Cultural Research Office Publications.

[19] Salehi Amiri, R. (2007). *Cultural concepts and theories*. Tehran: Ghoghnoos press.

[20] Bashir, H. (2008). New semantics of communication: preparing for a deeper understanding of the relationship between culture and media. *Cultural Research Journal, 1*(3), 131-155.

[21] Negarestan, F., Teymouri, M., & Atashinbar, M. (2010). Landscape theory, an approach to identity continuity in the process of urban renewal. *Bagh-e Nazar Journal, 14*, 59-68.

[22] Zukin, S. H. (2001). Urban culture: Whose city? Whose culture? Translation: Asadi, A. *Journal of Urban and Rural Management, 8*, 18-31.

[23] Rapoport, A. (1982). Urban design and human systems: on ways of relating the building to the urban fabric. Human and energy factors in urban planning: a systems approach. *Series D: Behavioural and Social Sciences - 12. Proceedings of the NATO Advanced Study Institute*. https://doi.org/10.1007/978-94-009-7651-1_12

[24] Corbett, N. (2014). *Transformation of cities Renaissance of urban squares*. Translation: Alizadeh, H. & Keshavarzi, Sh. Tehran: Urban Development and Improvement Organization Publications.

[25] Berdi Anamoradnejad, R. (2011). *Introduction to Urban Squares. Mazandaran*: Mazandaran University Press.

[26] Soleimani, A. R. & Asadi, M. (2017). *Environmental psychology (ethics, behavior, and urban design).* Tehran: Tahan Press.

[27] Ramon, G., Dolors, M., Ortiz, A., & Prats, M. (2004). Urban planning, gender and the use of neighborhood of Barcelona. *Journal of Cities, 21*(3), 215-223. https://doi.org/10.1016/j.cities.2004.03.006

[28] Naghizadeh, M. (2018). *Location in the good public domain of the city*. Tehran: University Jahad Publications.

[29] Saeidnia, A. (1999). *Municipal Green Book, Volume One: Urban Planning.* Tehran: Publications of the Municipalities Organization.

[30] Lau, H. M. (2014). *Investigating the small urban open spaces at high-density cities: A case study of Hong Kong*. (Master). UPPSALA Universitet.

[31] de Cillo Malufe Spignardi, M. (2020). Lively Urban Spaces. In: Ghosh M. (eds) *Perception, Design and Ecology of the Built Environment*. Springer Geography. Springer, Cham. https://doi.org/10.1007/978-3-030-25879-5_24

[32] Gehl, J., Johansen, L., & Reigstad, S. (2006). Close encounters with buildings. *Urban design international, 11*(1), 29-47. https://doi.org/10.1057/palgrave.udi.9000162

[33] Montgomery, J. (1998). Making a city: urbanity, vitality, and urban design. *Journal of Urban Design, 3*(1), 93-117. https://doi.org/10.1080/13574809808724418

[34] Mc Guire, N. (2017). Tactical urbanism: A plan for the revitalization of vacant and decrepit spaces. *The Equilibrium, 3*(1), 16-23. https://doi.org/10.5070/Q23141220
[35] Shaftoe, H. (2008). *Convivial Urban Spaces, Creating effective public spaces*. London: Earthscan in the UK and USA.
[36] Abbaszadeh, S. H. & Gohari, H. (2014). Meaningful spaces and social squares in Islamic urban planning are a lost element (interactive spaces) in Iranian-Islamic metropolises today. *Journal of Sustainable City, 1*, 164-191.
[37] Thornton, W. (2016). Differentiating small urban spaces as a type and idea. *PhD Thesis*, The University of Auckland.
[38] Joardad, S. D. & Neill, L. W. (1978). The subtle differences in the configuration of small public spaces. *Landscape Architecture Journal, 68*(6), 487-491.
[39] Carmona, M., de Magalhães, C., & Hammond, L. (2008). *Public space: the management dimension*: Psychology Press. https://doi.org/10.4324/9780203927229
[40] Tehran Studies and Planning Center. (2018). *Tehran Urban Space Management Strategic Document*. Danesh Shahr Publications.

Authors' contacts:

Parvin Partovi, Professor
University of Art,
56, Sakhai St., Hafez ave., Tehran 1136813518, Iran

Kebria Sedaghat Rostami, PhD candidate in Urban Planning
(Corresponding Author)
University of Art,
56, Sakhai St., Hafez ave., Tehran 1136813518, Iran
kebriasedaghat@chmail.ir

Amir Shakibamanesh, Associated Professor
University of Art,
56, Sakhai St., Hafez ave., Tehran 1136813518, Iran

ISSN 1846-6168 (Print), ISSN 1848-5588 (Online)
https://doi.org/10.31803/tg-20210518000021

Original scientific paper

Improving the Performance of Distance Relay Using Wavelet Transform

Zeynab Mohabati, Maryam Khoddam*

Abstract: With proliferation of power grids, different types of faults are more likely to occur. The purpose of system protection relays is to detect abnormal signals that indicate faults in the transmission system and to separate the fault section from the rest of the system to prevent the fault from propagating to other parts of the system. Proliferation of electronic devices led to creation of digital relays made of microprocessors. Hence, analog measurements are converted into digital signals for processing by microprocessors. Air grids are more likely to cause faults than other components of the power system; thus, disturbances affecting the system must be detected quickly and accurately. Therefore, the problem of fault detection and classification is an important factor for economic exploitation of the power grid. Accurate fault handling results in faster repair operations, better system availability, lower operating costs and timesavings. The proposed design in this study was based on detecting the type of fault caused in transmission lines. In order to improve the condition of the relays in the transmission grid, analysis of the signals reached to the relay on both sides of the line was used to detect the fault and its type. The main purpose was to quickly detect the type of fault using wavelet transform. For this purpose, the signal was sampled after the fault occurs and the feature signal was extracted after analysis by wavelet transform. These features were included in the decision tree classifier and the type of the fault was decided.

Keywords: decision tree algorithm; parallel transmission line protection; transmission line error detection and classification; wavelet transform

1 INTRODUCTION

Transmission lines are one of the main elements of the power system that connects production to consumption. Lines are spread over a large area and have a variety of faults. Current power systems, including factors that interact with each other in complex ways, may cause system faults [1]. Line faults may be caused by a variety of reasons such as lightning, sparks, birds, storms, snow and ice. Deformation of insulating materials can also cause short circuit faults. Line protection against faults is an important principle in system protection. Because lines are important components of a power system, its protection is essential to ensure system stability and reduce equipment damage due to short circuits that may occur in transmission lines. Continuity of this system is very important to achieve reliability of the power system. Air grids are more likely to fail than other components of the power system; faults in high voltage transmission lines also produce high frequency transients. These fault-induced transients have frequency, size, and damping rate that depend on many factors such as fault location, fault type, and system parameters. Fault occurs when two or more conductors come into contact with each other or with the ground in a three-phase system. These faults have devastating effects on power system equipment. The fault that occurs on the transmission line not only affects the equipment but also power quality. Therefore, it is necessary to determine the type of fault, locate it on the line, and eliminate it in the shortest possible time in order not to cause damage. As a result, disturbances affecting the system must be detected quickly and accurately. Rapid error detection, the ability to quickly separate the faulty line and protect it from harmful effects of the fault. To economically operate and sustain the power grid, it is important to detect, classify, and clear transmission line faults as soon as they occur. The accuracy of fault detection methods depends on measurement of voltage and current or its estimation method. Complexity of this is further intensified despite random changes in parameters such as fault type, fault location, fault angle, fault impedance, and so on.

With proliferation of power grids, different types of faults are more likely to occur. A typical fault elimination system includes a circuit breaker and a protection relay. The purpose of system protection relays is to detect abnormal signals that indicate faults in the transmission system and to separate the fault section from the rest of the system to prevent the fault from propagating to other parts of the system. In later years, faults were detected by electromechanical relays. The measured values, such as voltage and current, became mechanical force when they exceeded the predetermined threshold value, causing the relay to operate. Expansion of electronic devices led to creation of digital relays made of microprocessors. Hence, analog measurements are converted into digital signals for processing by microprocessors. Transmission line relays have three main functions: fault detection, fault classification, and fault location. Fault detection means detection of different modes of fault generation in transmission lines during which system current and voltage exceed the normal range; if the fault is not eliminated, it may result in equipment damage or even instability in the power grid and system collapse. Failure classification is detection of fault type. In fact, at this stage, detection of faulty phase or phases in order to correctly cut the faulty lines is done by considering the reduction of power outages frequently. After detecting the type of fault, fault location is determined in order to determine the exact location of the fault in order to send personnel and repair the faulty lines.

2 WAVELET TRANSFORM FUNCTION

Wavelets are mathematical transformations that divide information into different frequency components. The study is then performed on each component with a resolution that is related to waveform scale. It has the advantage over classical Fourier methods in analysis of physical situations

where the signal contains discontinuities or sharp spikes. Wavelets have been developed independently in the fields of mathematics, quantum physics, electrical engineering, and seismology. Exchange between these areas has led to newer applications of wavelets in image processing, perturbations, radar, and earthquake prediction in recent decades. The basic idea of wavelets is to analyze them on a scale basis. This idea does not seem very new. Because it was discovered in early 1800 that Fourier could create other functions by substituting sine and cosine functions. Wavelet algorithms process information at different scales and resolutions. If a signal is viewed through a large window, its basic features can be accessed. Similarly, if a signal is viewed through a smaller window, more accurate and detailed features can be obtained. For decades, scientists have sought to achieve more functions like sines and cosines that form the basis of Fourier analysis for variable signals. Limited studies have been published on approximation of sharp spikes, but with wavelet analysis, it is possible to use approximate functions located in finite regions. The wavelet analysis process is actually the matching of a sample function called parent wavelet with original signal function. Transient-state analysis is performed with a high-frequency and contracted parent wavelet sample, while permanent-state frequency analysis is performed with an open and low-frequency sample of a parent wavelet. Thus, the main signal or function can be displayed in terms of wavelet expansion.

As noted, wavelet transform has different base functions from the Fourier transform, which has a limited energy, leading to localization of these functions in the analyzed range. Each parent wavelet also has a specific and limited range of frequencies, which results in extraction of these limited frequencies in each analysis range. These features make the wavelet transform very efficient for extracting non-static features. Fast Fourier transform and discrete wavelet transform are both linear operators that produce a data structure. Both transformations can work to convert a function from one space to another. For fast Fourier transform, this new domain includes base functions including sine and cosine functions; for wavelet transform, this new domain involves much more complex functions called wavelet or parent wavelet. The most important difference between the two types of transformation is that wavelet functions are centralized, whereas cosine and sine functions of the Fourier transform are not. One advantage of wavelet transformations is that the windows are variable.

In order to separate the signal discontinuities, very short base functions are required, and at the same time, very long base functions will be responsible for analyzing the more detailed frequencies. One-way to access, this information is to have short high frequency base functions and long low frequency base functions. This is exactly what a wavelet transform creates. Another point to keep in mind is that wavelet transforms, as Fourier transforms, do not have a single set of base functions that use only finite sine and cosine functions. Wavelet functions have an infinite series of base functions. Wavelet analysis therefore provides access to information that is obscured by other time-frequency methods such as Fourier analysis. If the original signal is well known, then the wavelet type is easily chosen, but generally the signals are not well known in advance. Clearly, if the type of parent wavelet is chosen correctly, predictive efficiency of the model will increase. In this regard, there are various wavelet generation algorithms that can match the wavelets with the criteria defined by the user.

Continuous wavelet transform of the signal $f(t)$ is:

$$CWT(a,b) = \int_{-\infty}^{\infty} f(t)\Psi_{a,b}(t)\mathrm{d}t \tag{1}$$

$$\Psi_{a,b}(t) = \frac{1}{\sqrt{a}}\Psi\left(\frac{t-b}{a}\right) a, b \in \mathbb{R};\ a \neq 0 \tag{2}$$

The function $\Psi(t)$ is the parent function or wavelet, and a and b are dilation and translation parameters, respectively. Wavelet transform is mainly used at k level because it can be effectively performed using two filters (one is high-pass and the other is low-pass).

The number of decomposition levels depends on the sampling frequency and the frequency of which the information is important. The results are sampled with a coefficient of two reductions to reduce the computational load. Two identical filters are used to output the low-pass filter from the previous step. The high-pass filter is taken from the wavelet function (parent wavelet) and details are measured at a specific input. At the other side, the low-pass filter receives the input signal. This idea is shown in Fig. 1.

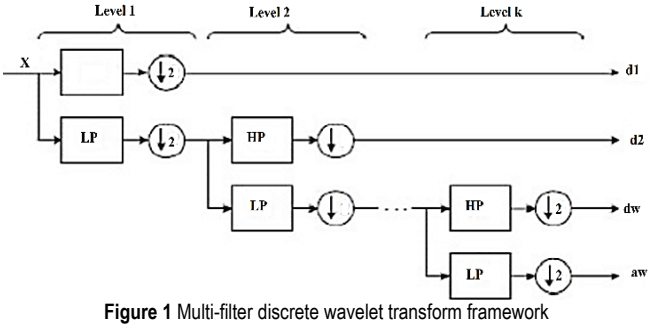


Figure 1 Multi-filter discrete wavelet transform framework

3 C4.5 ALGORITHM

ID3 algorithm is an algorithm for building a decision tree. In this algorithm, the concept of irregularity is used to classify the data, and the algorithm tends to minimize the amount of irregularity in the upper nodes of the tree so that a tree with a minimum height can be obtained. Thus, irregularity is first calculated for all features of the raw data and then the feature with the highest utility is chosen as the root. Utility of each feature is then calculated, in which the amount of irregularity remaining in the classes is due to the use of a feature, which can be obtained by summing the probability of occurrence of each division. This algorithm is only able to classify data with a range of discrete and limited features and is not efficient for noisy and distorted data. Completed C4.5 algorithm is ID3 algorithm [2-4]. This algorithm is also able to classify continuous and noisy data. For this purpose, the data is first sorted; then utility values

are obtained for all cases in which it is possible to separate the sorted data, and choose the separator corresponding to the largest value of utility as a separator [5-7].

4 RANDOM FOREST (RF) ALGORITHM

When forming a decision tree, a small change in learning patterns can cause fundamental changes in the structure of that tree. To overcome these problems, a random forest algorithm is proposed, which is a learning method based on a bunch of decision trees. In this method, classifier outputs become much more powerful than noisy data. The random forest prediction model is based on averaging the results of all relevant decision trees. By using this method, useful information about importance of each variable will be obtained and thus the variables with the greatest impact on the dependent variable are determined. In this method, the number of m predictors are randomly chosen for bootstrap sampling from the training and tree production set. After producing a large number of trees, each tree votes for the most popular class. By merging the votes of different trees, a class is predicted for each sample. The very high accuracy of this method is one of its advantages, while it can work well with a large number of inputs [8, 9].

Jamali et al. [10] used several classifier algorithms to classify power quality disturbances and finally concluded that DT algorithms have higher accuracy and lower computational load compared to others.

5 THE PROPOSED METHOD

5.1 Validating the Proposed Method

Conventional validation methods can be divided into three categories. One method uses all the data both to train the classifier algorithm and to test it, which, in addition to possibility of over-fitting in the classifier, results in an optimistic algorithm error rate. The other method randomly breaks the data into two sets of training and testing, trains the algorithm, and then classifies it. This method may also not train the algorithm well and the exact error rate may not be obtained. Another method is to break the data into several classes. This type of validation is divided into three categories:

1) Random multiple sampling method in which the data set is divided into two subsets of training and testing. The model is then trained using training data and the result is validated using test data. This procedure is repeated several times and average of the results is considered as the final estimate. The advantage of this method is that the ratio of training and test data in each run does not depend on the number of subsets. The disadvantage of this method is that some data may never be used for validation and others may be used multiple times. In other words, subsets can overlap.
2) Another method of breaking is called *k*-fold, in which the data is randomly split into *k* subsets. Of these *k* subsets, one is used at a time for validation and the other *k*–1 for training. This procedure is repeated *k* times and all data is used exactly once for training and once for validation. Finally, the average result of these *k* validations is chosen as a final estimate. Ten folds are typically used.
3) Another method is called leave-one-out. As the name implies, at each stage one of the data is left out for validation and the rest of the data is used for training. This method is actually the *k*-fold method in which *k* is considered equal to the number of data. This method is computationally expensive because the training and validation process is repeated over and over again [11, 12]. In this study, validation was performed using the *k*-fold method with a value of *k* equal to 10.

5.2 Implementing the Proposed Method

Transient states in power systems generally have non-periodic, short-lived, and non-stationary waveforms. Wavelet transform can decompose signals into different frequency ranges. Discrete wavelet transform of voltage and current signals is used to extract the feature vector required for classification. The purpose of feature extraction is to determine the unique characteristics of a voltage or current waveform that can be used to detect the type of fault.

In this study, different fault scenarios will be simulated first using MATLAB software; in order to create a relay with maximum speed and accuracy, some parent wavelets from the Daubechies family that are widely used in the field of power system disturbances detection will be studied and examined. db4 from the Daubechies family will be considered as parent wavelet. The fault signals obtained from the grid simulation will be decomposed separately using each parent wavelet to the required number of levels. The coefficients obtained from the voltage or current signals will be decided by discrete wavelet transform, as a feature vector to the tree classifier and the decision tree will be trained using WEKA software. WEKA software is a reliable software in machine learning and data mining systems [13].

5.3 The Studied Grid

In order to implement the fault type detection project in the transmission grid, a two-circuit line grid of the transmission grid will be considered with the same start and end. The relay is installed at the beginning, end of this line according to Fig. 1, and will adapt the required signals from the expected transmission line at any time [14].

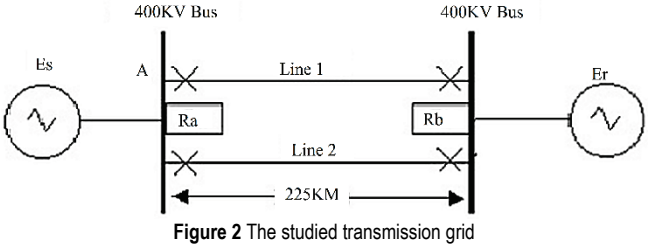


Figure 2 The studied transmission grid

In the above grid, 20 types of faults (10 types of faults per line) including three single phase-to-ground faults, three double phase-to-ground faults, three double-phase faults and three-phase faults will be simulated in different scenarios.

These scenarios will vary in terms of fault time (fault angle), fault location and fault resistance. Simulated current or voltage signals will be stored in the Simulink section of MATLAB software and uploaded in its coding section for analysis using wavelet transform. After wavelet analysis and feature extraction and unification, the available data will be inserted in Weka software in order to classify and detect the type of fault. In this software, the best features are chosen by different methods and the data is classified using the two methods expressed by decision tree algorithm, and the fault classes are separated from each other and the type of fault is determined. Naturally, the type of feature and choosing the best features will affect the final accuracy obtained. In fact, Weka output will determine how accurately the proposed algorithm is able to detect the type of fault. The parameters for the simulated lines are as shown in Tab. 1.

As shown in Tab. 1, the first part of the line is 225 km double-circuit line and the next part is 100 km single-circuit line that connects the two parts of the system. The voltage at both ends of the lines is 400 kV and the short circuit level for both sides is 200 MV. A load angle of 30 degrees is also considered so that nominal current of 730 amps can pass through each circuit of the double-circuit line.

Table 1 Transmission line parameters [5]

Parameter	First part of line (225 km double-circuit line)	Second part of line (100 km single-circuit line)
R0	81.32 Ω	36.14 Ω
R1	81.16 Ω	36.62 Ω
X0	310.48 Ω	137.99 Ω
X1	108.82 Ω	48.36 Ω

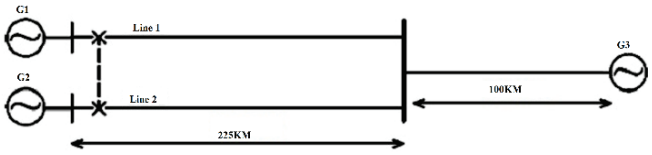


Figure 3 Single line diagram of the simulated system [17]

The simulated circuit of the system in the Simulink section of Matlab software is as shown in Fig. 3.

As shown in Fig. 3, the double-circuit line is simulated separately at intervals of 22.5, 90, 90 and 22.5 km. In fact, these distances provide 10, 50 and 90% of the line to simulate the fault in different locations.

6 SIMULATION OF FAULT TYPES

Since there can be twenty faults in two-circuit lines (10 faults per circuit), the relay of each circuit must be able to correctly detect faults of the second circuit, in addition to correctly detecting its own faults and commanding a faulty circuit to disconnect, and do not command disconnection. In fact, since the ends of this double-circuit line are connected as shown in Fig. 3, the fault in one circuit will affect the other line as well and increase its current. Therefore, it is obvious that the desired protection is achieved when the disconnection is commanded only in one circuit (circuit in which the fault occurred) and the second circuit continues to operate. Because the fault may occur anywhere on the line, at any angle of the line voltage, and with any different fault resistance, comprehensive information must be provided for various faults. For this purpose, three-phase current signals will be simulated at points 10, 50 and 90% of the line. Also at each point, the fault will be simulated separately at 0 and 90 voltage angles. Each fault will be considered with resistances of 0.001, 5, 10, 15 and 20 ohms.

As can be seen from the above, 300 signals for different types of faults will only be simulated at 10% of the first circuit line. In fact, these 300 signals will provide three-phase currents for 100 different fault scenarios at 10% of the line. The same will be simulated for 50 and 90% of the line, which will result in 300 fault scenarios from all simulated faults. In all scenarios, the simulated fault of the three-phase current signals of the first circuit and the second circuit will be removed, which will provide a total of 1800 signals (900 signals from the first circuit and 900 signals from the second circuit) to analyze and extract the features. In fact, the first circuit relay must detect 300 fault scenarios in the first circuit and command disconnection after detecting the type of fault; the second circuit relay, although it will observe fault current signals, must detect the fault in the first circuit and not command disconnection.

As noted earlier, single-phase faults including AG, BG, CG, double phase-to-ground faults such as AGB, ACG, BCG, double-phase faults such as AB, AC, BC and three-phase ABC fault will be simulated in two circuits. In order to train the decision tree algorithm, for each of the above disturbances, 30 different simulation scenarios occur in the proposed grid and waveform of three-phase currents is stored. These simulations differ from points of view such as fault time and fault resistance and fault location, and no two scenarios will have the same waveform.

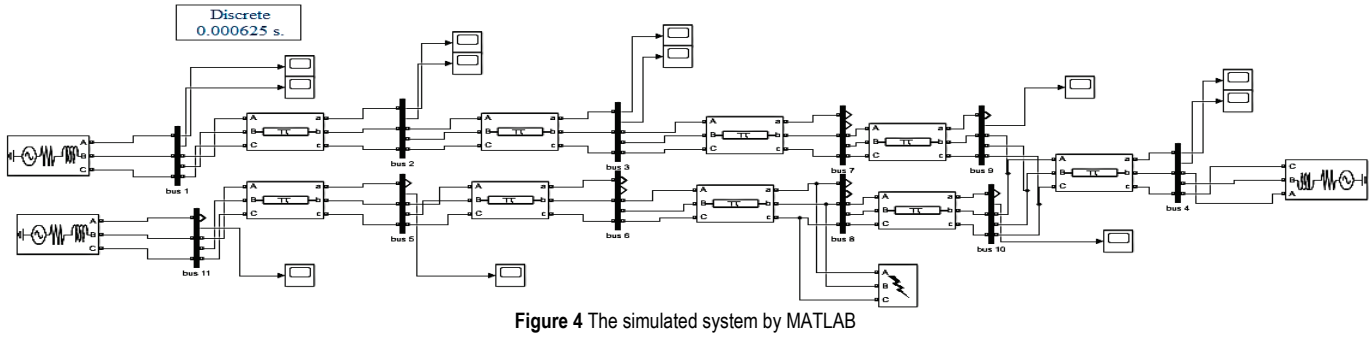


Figure 4 The simulated system by MATLAB

The simulated forms of these disturbances are generated and stored by the Simulink and then analyzed using wavelet transform and the feature is extracted from them. In the following, the three-phase current waveforms for various types of faults in 10% of the first circuit are presented from the viewpoint of the relay embedded in the first circuit.

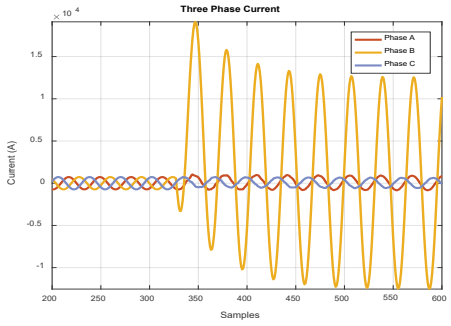
Fig. 4 shows faults of AG, BG, AC, ABG, ACG, BCG, AB, AC, BC and ABC in location of 10% of the first circuit and with fault resistance of 0.001 ohm seen from the relay at the beginning of the first circuit line. Note that the sampling frequency of the relay is 1.6 kHz. As a result, there are 1600 samples for 1 second. The simulations are done for half a second (800 samples) and the shapes are drawn for better clarity between the ranges of 200 to 600 samples.

6.1 Classification despite Noisy Data

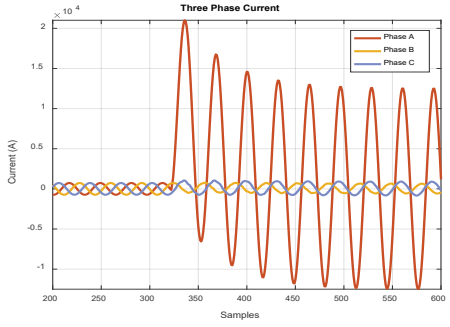
Despite the noise in the data, accuracy of classifiers will decrease. Because the presence of signal distortion causes the acquired features to lose their efficiency in separating the classes. Output accuracy will vary according to different values of signal to noise ratio (SNR) [14, 15]. In this study, SNR values of 35 and 45 dB will be investigated [16]. The classification results with different features and different classification methods and 45 dB noise are presented in Tab. 2. It is worth noting that the results of this section will be presented with 24 features (optimal value of features in classification of phenomena obtained in the previous section). The dispersion matrix is displayed only for the decision tree algorithm with 10 trees, which provided the best performance in terms of accuracy and speed in the previous section.

Table 2 Accuracies of classifiers with reduced features despite noise

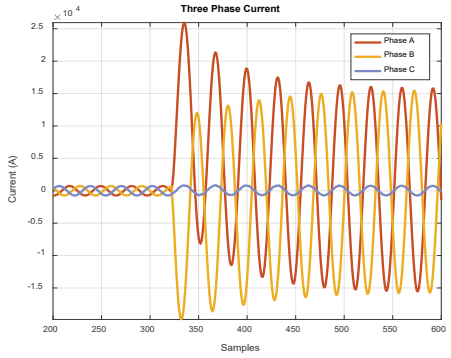
Number of features: 24; noise of data: 45 dB Unification method: Zscore; validation method: k = 10, k-fold			
Accuracy based on classification method (%)			
RF (100 tree)	RF (10 tree)	RF (5 tree)	C4.5
98.5	98.5	96.83	95



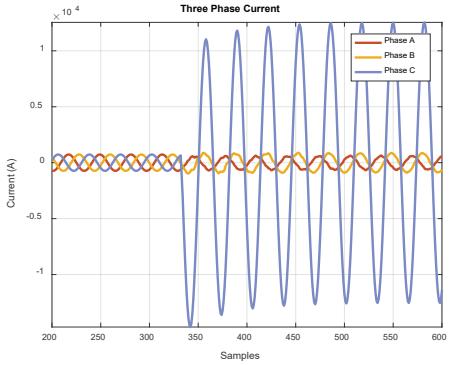
BG fault in 10% of the first circuit seen from the first circuit relay



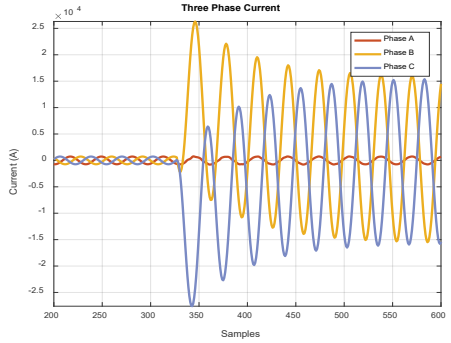
AG fault in 10% of the first circuit seen from the first circuit relay



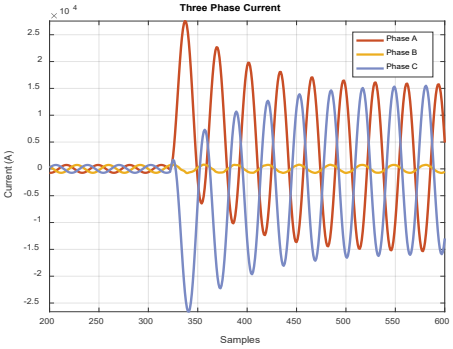
ABG fault in 10% of the first circuit seen from the first circuit relay



CG fault in 10% of the first circuit seen from the first circuit relay

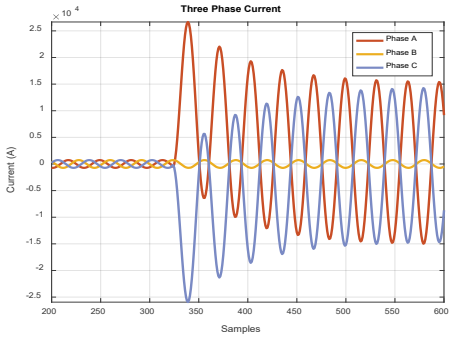


ACG fault in 10% of the first circuit seen from the first circuit relay

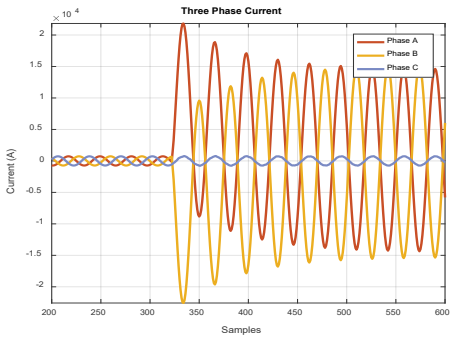


BCG fault in 10% of the first circuit seen from the first circuit relay

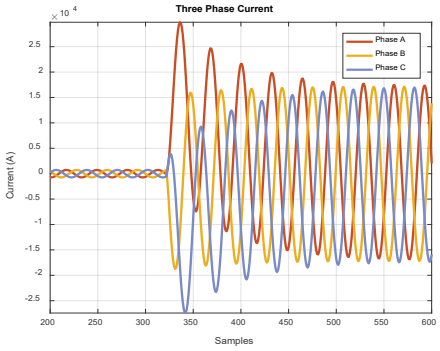
Figure 5 Results of fault simulation



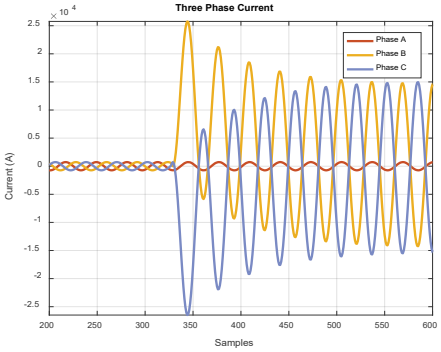
AC fault in 10% of the first circuit seen from the first circuit relay



AB fault in 10% of the first circuit seen from the first circuit relay



ABC fault in 10% of the first circuit seen from the first circuit relay



BC fault in 10% of the first circuit seen from the first circuit relay

Figure 6 Results of fault simulation (continued from previous page)

It can be seen that despite noise in the data, accuracy of the classifiers decreases, but despite the noise of 45 dB, the decision tree with 10 trees still performs well in classification of faults. The dispersion matrix in this case, as shown in Fig. 5, indicates that only 8 out of 600 cases in the classification are detected incorrectly.

```
  a   b   c   d   e   f   g   h   <-- classified as
 30   0   0   0   0   0   0   0 |   a = AGm1
  0  30   0   0   0   0   0   0 |   b = BGm1
  0   0  30   0   0   0   0   0 |   c = CGm1
  0   0   0  60   0   0   0   0 |   d = ABm1
  0   0   0   0  60   0   0   0 |   e = ACm1
  0   0   0   0   0  56   0   4 |   f = BCm1
  0   0   0   0   0   0  30   0 |   g = ABCm1
  0   0   0   2   1   2   0 295 |   h = m2
```

Figure 7 Confusion matrix of RF algorithm with 10 trees despite the noise in the data

In order to further investigate, the amount of noise is increased and SNR is reduced to 35 dB. With this amount of noise in the current signals, the accuracies obtained in separation of fault scenarios will be according to the table below.

It is observed that output accuracies will decrease with increasing noise in the data. It can be seen from the table above that accuracy of the algorithm will not decrease with 100 trees in the decision tree algorithm. As a result, in case of high noise in the data, the number of trees can be increased in order not to reduce the classifier accuracy, in addition to noise reduction methods. The dispersion matrix for the decision tree with 10 trees is also shown in Fig. 7.

Table 3 Accuracies of classifiers with reduced features despite noise

Number of features: 24; noise of data: 35 dB Unification method: Zscore; validation method: k = 10, k-fold			
Accuracy based on classification method (%)			
RF (100 tree)	RF (10 tree)	RF (5 tree)	C4.5
98.5	98	96	94.66

```
  a   b   c   d   e   f   g   h   <-- classified as
 30   0   0   0   0   0   0   0 |   a = AGm1
  0  29   0   0   0   0   0   1 |   b = BGm1
  0   0  29   0   0   1   0   0 |   c = CGm1
  0   0   0  60   0   0   0   0 |   d = ABm1
  0   0   0   1  59   0   0   0 |   e = ACm1
  0   0   0   0   0  55   0   5 |   f = BCm1
  0   0   0   0   0   0  30   0 |   g = ABCm1
  0   0   0   2   1   1   0 296 |   h = m2
```

Figure 8 Confusion matrix of RF algorithm with 10 trees despite the noise in the data

7 CONCLUSION

Analysis and fault detection in power systems raises issues related to power systems, including: significant economic impacts for operators, maintenance agents, and power industry. For this reason, the search and development of new algorithms and methods to solve this problem has been considered. Parallel transmission lines are widely used in power grids to transfer high power and increase system reliability. However, in terms of protection, parallel transmission lines require special considerations to single-circuit transmission lines. When considered as an independent circuit from a conventional distance relay to protect parallel lines, mutual coupling between two circuits

affects the impedance measured by the relay. This will reduce the range or increase the relay range depending on grid features. This study suggests a method to improve the protective performance of distance relays in transmission grid based on wavelet transform and decision tree. Due to shortcomings of Fourier transform in the field of fault detection, the use of wavelet transform in the field of fault detection or changes in signals of the power system has attracted much attention in recent years. In fact, this method is a mathematical conversion based on conversion of a signal into various types of scaling by another function called parent wavelet.

The most important reason for using wavelet transform is high resolution and time and frequency precision of this transformation. Wavelet transform is able to show some signal properties that other transformations are not able to show and destroy these properties during transformation. These properties include high slopes in the function, breakpoints in the function, discontinuities of higher order derivatives of the function. Accordingly, it can be concluded that wavelet transform provides a partial and regional view of the function. This property increases the accuracy of the work while a transformation like Fourier provides an overview of the signal period. Each function used as parent wavelet has a mean of zero and a unit energy, and as proposed, this transformation provides a frequency time form of the signal. This study used discrete wavelet transform as a package. Since the 1.6 kHz signal sampling frequency is chosen, this transform is able to extract signal information up to 800 Hz (half the sampling rate) according to the Nyquist theorem. By breaking the wavelet transform up to 4 levels, we will achieve 50 Hz nodes. Because the generated fault signals, including single-phase fault, double phase-to-ground, double-phase, and three-phase faults, do not have high frequencies in independent circuits, 0 to 50 Hz node in the fourth level of wavelet transform containing information about the main component of the signal is chosen to extract features.

After extracting various statistical features and unifying them, classification was done using two methods of decision tree algorithm. These two methods differ in terms of tree production and pruning, the ability to classify with high accuracy despite the noise, and how to use the features in tree production. Random forest uses a set of trees produced to determine the final class, which makes this method more resistant to noise in the data. After simulating 8 classes of disturbances and generating 1800 different signals and 600 fault scenarios for classes and extracting and unifying features, a 600×27 matrix was formed and given to WEKA software. Then, the algorithm was tested by k-fold, $k = 10$. The results were investigated under different conditions despite the noise in the data and with different number of features. Considering the presented results, it can be argued that if the features extracted from wavelet coefficients of 50 Hz node are used and the random forest method is used, it is possible to classify the faults with maximum accuracy and correctly detect the fault type. As only half, a cycle of post-disturbance data is used and the presented features are used and computational load of the random forest method is low, it can be acknowledged that the proposed method, in addition to low computational load, offers high speed and accuracy. As wavelet transform coefficients are sensitive to noise in the data, the accuracy obtained despite 35 and 45 dB noises were also studied. Despite the noise in the data, signal denoising methods should be used before extracting the feature in order not to reduce the final accuracy, in which case the processing and calculation operations of the algorithm will be increased. A higher number of features or noise-free classification methods can be used. By these results, it can be observed that the algorithm will only have 2% fault and acceptable accuracy despite 35 dB noise in data with 24 features and without using denoising methods.

8 REFERENCES

[1] Coelho, V. N., Cohen, M. W., Coelho, I. M., Liu, N., & Guimaraes, F. G. (2017). Multi-agent systems applied for energy systems integration: State-of-the-art applications and trends in microgrids. *Applied energy*, *187*, 820-832. https://doi.org/10.1016/j.apenergy.2016.10.056

[2] Ranjbar, S., Farsa, A. R., & Jamali, S. (2020). Voltage-based protection of microgrids using decision tree algorithms. *International Transactions on Electrical Energy Systems*, *30*(4), e12274. https://doi.org/10.1002/2050-7038.12274

[3] Nijhawan, V. K., Madan, M., & Dave, M. (2017). The Analytical Comparison of ID3 and C4. 5 using WEKA. *International Journal of Computer Applications*, *167*(11), 1-4. https://doi.org/10.5120/ijca2017914286

[4] Mienye, I. D., Sun, Y., & Wang, Z. (2019). Prediction performance of improved decision tree-based algorithms: a review. *Procedia Manufacturing*, *35*, 698-703. https://doi.org/10.1016/j.promfg.2019.06.011

[5] Li, H., Deng, C., Zhang, Z., Liang, Y., & Wang, G. (2021). An adaptive fault-component-based current differential protection scheme for distribution networks with inverter-based distributed generators. *International Journal of Electrical Power & Energy Systems*, *128*, 106719. https://doi.org/10.1016/j.ijepes.2020.106719

[6] Casagrande, E., Woon, W. L., Zeineldin, H. H., & Svetinovic, D. (2013). A differential sequence component protection scheme for microgrids with inverter-based distributed generators. *IEEE Transactions on smart grid*, *5*(1), 29-37. https://doi.org/10.1109/TSG.2013.2251017

[7] Mahamedi, B. & Fletcher, J. E. (2019). Trends in the protection of inverter-based microgrids. *IET Generation, Transmission & Distribution*, *13*(20), 4511-4522. https://doi.org/10.1049/iet-gtd.2019.0808

[8] Zhao, Y., & Zhang, Y. (2008). Comparison of decision tree methods for finding active objects. *Advances in Space Research*, *41*(12), 1955-1959. https://doi.org/10.1016/j.asr.2007.07.020

[9] Pranckevičius, T. & Marcinkevičius, V. (2017). Comparison of naive bayes, random forest, decision tree, support vector machines, and logistic regression classifiers for text reviews classification. *Baltic Journal of Modern Computing*, *5*(2), 221-232. https://doi.org/10.22364/bjmc.2017.5.2.05

[10] Jamali, S., Farsa, A. R., & Ghaffarzadeh, N. (2018). Identification of optimal features for fast and accurate classification of power quality disturbances. *Measurement*, *116*, 565-574. https://doi.org/10.1016/j.measurement.2017.10.034

[11] Jiang, G. & Wang, W. (2017). Error estimation based on variance analysis of k-fold cross-validation. *Pattern Recognition*, *69*, 94-106. https://doi.org/10.1016/j.patcog.2017.03.025
[12] Rodriguez, J. D., Perez, A., & Lozano, J. A. (2009). Sensitivity analysis of k-fold cross validation in prediction error estimation. *IEEE transactions on pattern analysis and machine intelligence*, *32*(3), 569-575. https://doi.org/10.1109/TPAMI.2009.187
[13] Jamehbozorg, A. & Shahrtash, S. M. (2010). A decision-tree-based method for fault classification in single-circuit transmission lines. *IEEE Transactions on Power Delivery*, *25*(4), 2190-2196. https://doi.org/10.1109/TPWRD.2010.2053222
[14] Pourjabar, S. & Choi, G. S. (2020). CVR: A Continuously Variable Rate LDPC Decoder Using Parity Check Extension for Minimum Latency. *Journal of Signal Processing Systems*, 1-8. https://doi.org/10.1007/s11265-020-01597-0
[15] Pourjabar, S. & Choi, G. S. (2021). A High-Throughput Multi-Mode LDPC Decoder for 5G NR. arXiv preprint arXiv:2102.13228.
[16] Osman, A. H. & Malik, O. P. (2004). Protection of parallel transmission lines using wavelet transform. *IEEE Transactions on power delivery*, *19*(1), 49-55. https://doi.org/10.1109/TPWRD.2003.820419

Authors' contacts:

Zeynab Mohabati
Department of Electrical Engineering,
Khomein Branch, Islamic Azad University,
Khomein, Iran

Maryam Khoddam, Assistant Professor
(Corresponding Author)
Department of Electrical Engineering,
Khomein Branch, Islamic Azad University,
Khomein, Iran
maryamkhoddam@chmail.ir

ISSN 1846-6168 (Print), ISSN 1848-5588 (Online)
https://doi.org/10.31803/tg-20210805120621

Original scientific article

Suitability of Recycled PLA Filament Application in Fused Filament Fabrication Process

Tomislav Breški, Lukas Hentschel, Damir Godec*, Ivica Đuretek

Abstract: Fused filament fabrication (FFF) is currently one of the most popular additive manufacturing processes due to its simplicity and low running and material costs. Support structures, which are necessary for overhanging surfaces during production, in most cases need to be manually removed and as such, they become waste material. In this paper, experimental approach is utilised in order to assess suitability of recycling support structures into recycled filament for FFF process. Mechanical properties of standardized specimens made from recycled polylactic acid (PLA) filament as well as influence of layer height and infill density on those properties were investigated. Optimal printing parameters for recycled PLA filaments are determined with Design of Experiment methods (DOE).

Keywords: design of experiment; fused filament fabrication; polylactic acid; recycling

1 INTRODUCTION

Additive manufacturing (AM) is evolving on a daily basis, especially with the emphasis on low-budget market since most of the general patents related to AM technologies are expired, or are about to expire [1]. Most affordable AM machines are working on a principle of Fused Filament Fabrication (FFF) which works on a principle of material extrusion through numerically controlled nozzle [2]. One of the drawbacks of the FFF process is that it needs support material for overhanging surfaces of the model during printing. After the print job is finished, support material can be mechanically removed or dissolved with appropriate solvent, but in most cases it is mechanically removed. As such, support material if not used in any other function after removal is waste material, but due to the nature of thermoplastics primarily used in AM, it can be recycled and reused in production of new products [3, 4].

Polylactic acid (PLA) is one of the most widely used 3D printing filament [5]. PLA is a semi-crystalline polyester produced by fermenting under controlled conditions of a carbohydrate source, like sugarcane or corn starch. Glucose fermentation produces L-lactic acid which is a basic constituent of PLA [6]. PLA filament is cheap and in most cases it is not viable for standard user to recycle it, but with latest research in recycling processes, PLA recycling is proving more valuable than ever. Lifecycle analysis procedures related with filament recycling have shown that distributed approaches in filament recycling can further decrease filament prices without sacrificing any material properties [7]. Recycling equipment such as shredders and extruders are expensive for personal use, but with establishment of distributed centres across the countries where standard users could bring their own waste and in return buy discounted recycled filament, initial investment in recycling equipment is feasible.

Circular economy is based on regeneration of the components and the materials. By utilising of the waste material as a participant in the manufacturing process, virgin materials usage is decreased. Circular economy distinguishes two standpoints: a biological cycle, which returns the waste to natural systems, and a technical cycle, which keeps the flow of the materials in cycles which regenerate other products or systems [8]. FFF processes can be observed as circular processes, since waste materials used in the FFF process can be recycled and used for printing of new parts. Materials flow for recycled filaments for 3D printers is shown in Fig. 1.

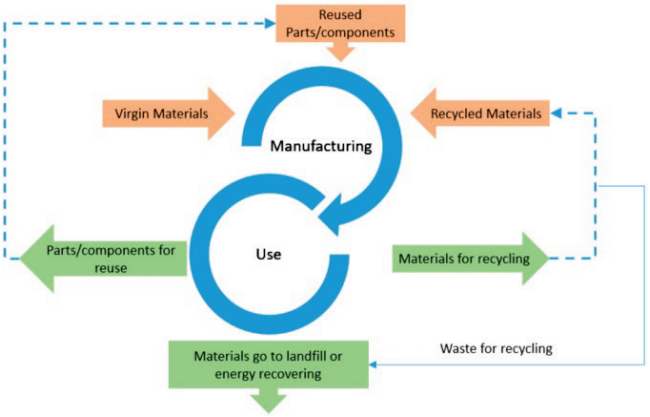


Figure 1 Materials flow for recycled filaments for 3D printers [8]

Mechanical properties of recycled filament are very dependent on number of recycling cycles [9], but with particular mixing of recycled material and virgin material, satisfactory material properties can be achieved even after 5 recycling cycles [10]. With repetitive recycling, elastic modulus of PLA remains constant, but strain at break is reduced up to 10% which needs to be taken into account. Also, rheological properties of the material tend to degrade with recycling cycles. Melt flow index (MFI) increases up to 6 times, which means that the recycled PLA filament tends to flow better with repetition of recycling cycles [11].

In order to provide a statistical background in material properties relationship with processing parameters, Design of Experiment (DoE) approaches have been used successfully in academia and industry. Processing parameters of PLA filament used on specific FFF machine can be calculated with great accuracy with modern DoE applications [12]. In this paper, DoE approach is utilised to find whether the recycled

PLA filament is appropriate for use on low-budget FFF machines from the standpoint of accurate mechanical properties prediction. In most cases, standard users of low-budget FFF machines change only the layer thickness and infill density in order to reduce material consumption and print time, so in this paper, these processing parameters are selected as influential parameters on measured responses of mechanical properties of dog-bone specimens, specifically tensile strength and elongation at break.

2 MATERIALS AND METHODS

2.1 Filament Production

Recycled PLA material was produced from shredded 3D printed samples and support structures on mechanical thermoplastics shredder (SHR3D IT, 3devo B.V, Utrecht, Netherlands). Due to the nature of the mechanical grinding process, shredded PLA particles vary in size and shape since on the mentioned shredder, only one mesh size can be used. Continuous filament production was not achieved with 3DEVO filament extruder, which was meant to be used as low-budget filament production system, due to the high variation of particles shape and size. Satisfactory geometrical filament properties were achieved with a single-screw extruder (FT-E20T-MP-IS, Dr. Collin GmbH, Ebersberg, Germany) coupled with Teflon conveyor belt (GAL-25, GEPPERT-BAND GmbH, Jülich, Germany) and a self-developed haul off and winding unit with processing parameters shown in Tab. 1.

Table 1 Filament extrusion parameters

T_1 (°C)	T_2 (°C)	T_3 (°C)	T_{nozzle} (°C)	Screw speed (rev/min)	Pressure (bar)
195	200	205	205	100	120

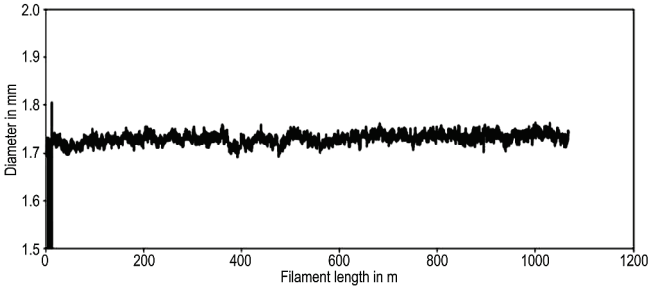


Figure 2 Diameter distribution of virgin PLA filament

During extrusion of the filaments from virgin PLA pellets and from recycled PLA shredded particles, it was observed that the recycled filament has increased variation of diameter which comes from size and shape variation of shredded PLA particles in comparison with virgin PLA pellets. Diameter distribution during extrusion of the virgin PLA filament is visible on Fig. 2, while diameter distribution during extrusion of the recycled PLA filament is visible on Fig. 4. Mean diameter of virgin PLA for the entire spool was 1,73 mm with standard deviation of 0,068 mm, while mean diameter of recycled PLA for the entire spool was 1,71 mm with standard deviation of 0,18 mm. Diameter histograms and ovality measurements are shown on Fig. 3 and Fig. 5. Extrusion process got interrupted at 170 mm of extruded filament, but afterwards the process was continuous and filament was extruded with satisfactory geometrical properties.

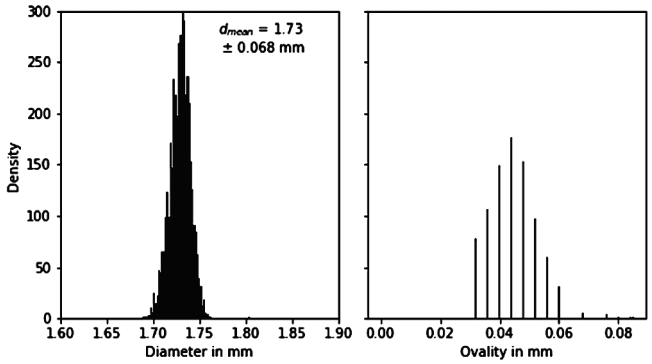


Figure 3 Histogram of the diameter and ovality of virgin PLA

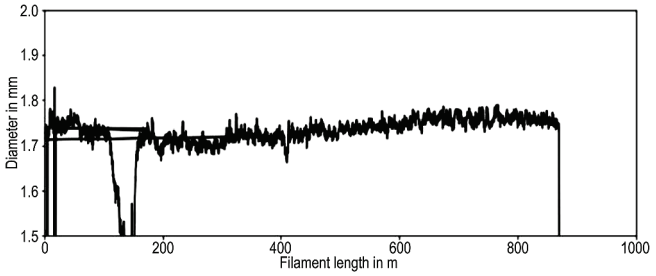


Figure 4 Diameter distribution of recycled PLA filament

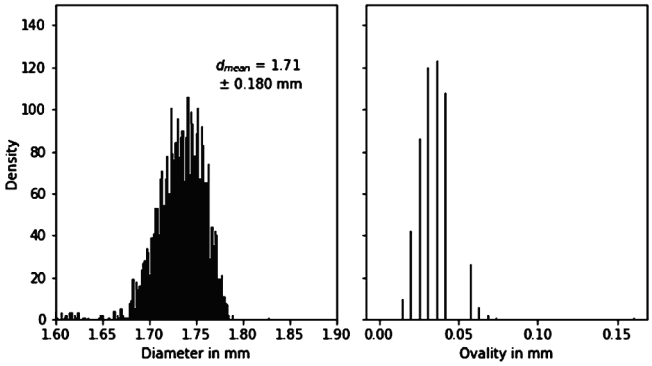


Figure 5 Histogram of the diameter and ovality of virgin PLA

2.2 FFF Process Parameters

PLA filament was extruded on an Original Prusa I3 MK3S fused filament fabrication machine (Prusa Research, Prague, Czech Republic) with installed nozzle diameter of 0,4 mm shown in Fig. 6. Flexible PEI sheet was used as a replaceable printing surface.

The software PrusaSlicer (Prusa Research, Prague, Czech Republic) was used to prepare the G-code for dog-bone specimens production with the following parameters which were kept constant through all trial runs:

- Rectilinear fill patterns for top and bottom layers
- Fill angle of 45 %
- Printing speed of 35 mm/s
- Extruder temperature of 210 °C
- Bed temperature of 60 °C.

Figure 6 FFF machine Prusa I3 MK3S

Parts for tensile tests were designed as dog-bone specimens compliant with ISO 527:2019 – type A, with dimensions shown in Fig. 7.

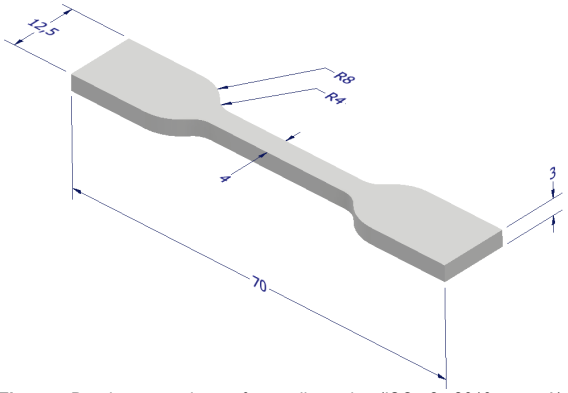


Figure 7 Dog-bone specimens for tensile testing (ISO 527:2019 - type A); dimensions in mm

2.3 Design of Experiment Analysis (DOE)

For analysis of the material properties two-level factorial Design of Experiment approach was used, which allows investigation of influences of certain parameters on measured responses, which in our cases are tensile strength (MPa) and elongation at break (%). Design space includes two factors, which are layer height (mm) and infill density (%), each at two levels which is visualised in Fig. 8.

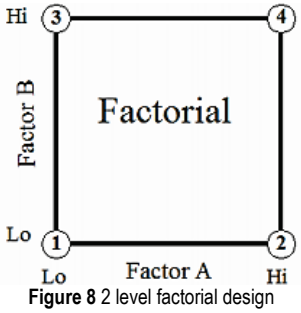


Figure 8 2 level factorial design

In order to increase statistical power of the design, additional points in the centre of the parameter space are added, and also 3 replicates for pure error calculation. Run list of 2 factor interaction DoE is shown in Tab. 2.

Table 2 2FI DoE runs

Run	Layer height (mm)	Infill density (%)
1	0,1	50
2	0,2	30
3	0,1	30
4	0,3	70
5	0,3	70
6	0,3	50
7	0,1	30
8	0,3	30
9	0,2	50
10	0,3	30
11	0,1	70
12	0,2	70

Three identical specimens were printed for each run, and their relative placement on the centre of the build platform is visible in Fig. 9.

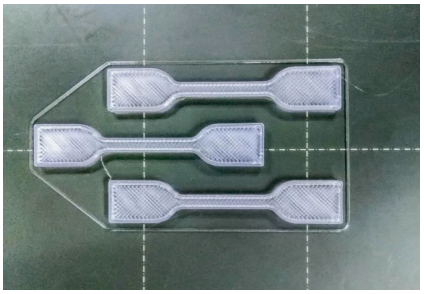


Figure 9 Printed tensile test specimens

Figure 10 Shimadzu AGS-X 10 kN with fitted dog-bone specimen

2.4 Tensile Testing

Tensile testing of 3D printed dog-bone specimens was performed on a universal static testing machine Shimadzu AGS-X 10 kN fitted with contact extensometer (Shimadzu Corp., Kyoto, Japan) which is shown in Fig. 10. Tensile strength (MPa) and elongation at break (%) was measured

and used as characterisation parameters for the mechanical properties of the printed dog-bone specimens only from recycled PLA filament since virgin PLA filament mechanical properties are widely available and well documented in literature. Specimens were tested at deformation speed of 2 mm/min at the temperature of 22 °C, and relative humidity of 50%.

During testing, specimens were breaking at the expected regions inside the extensometers which is shown in Fig. 11.

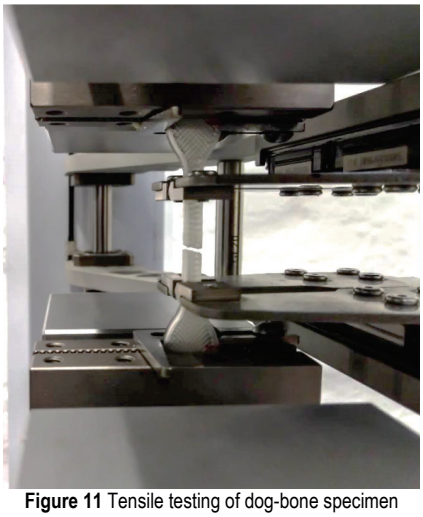


Figure 11 Tensile testing of dog-bone specimen

3 RESULTS AND DISCUSSION

Tensile testing results with included standard deviation (SD) of each run are shown in Tab. 3.

Table 3 Tensile testing results

Run	Tensile strength (MPa)	Elongation at break (%)
1	66,5 ± 1,5	6,8 ± 1,3
2	59,9 ± 3,5	5,4 ± 3,9
3	67,3 ± 0,7	7,2 ± 0,5
4	62,2 ± 1,1	6,9 ± 2,0
5	56,2 ± 1,3	6,8 ± 0,3
6	56,9 ± 1,9	7,4 ± 1,6
7	66,1 ± 0,7	6,3 ± 2,3
8	53,4 ± 2,6	7,0 ± 1,5
9	61,5 ± 0,5	7,4 ± 2,7
10	55,3 ± 1,3	8,4 ± 0,6
11	63,2 ± 3,2	10,4 ± 1,7
12	57,1 ± 1,7	8,3 ± 2,8

Tensile stress – strain diagram for all specimens of the DoE is shown in Fig. 12.

For statistical analysis of the tensile testing results the software Design Expert 11 (Stat – Ease Inc., Minneapolis, MN, USA) was used. Analysis of variance (ANOVA) and response surface models were used in order to determine significance of adjustable parameters during printing of recycled PLA and their linear interactions on the observed tensile properties. Furthermore, by utilizing the statistical methods included in Design Experiment 11, mathematical functions are evaluated, which can be used for prediction of the observed tensile properties in the DoE model space.

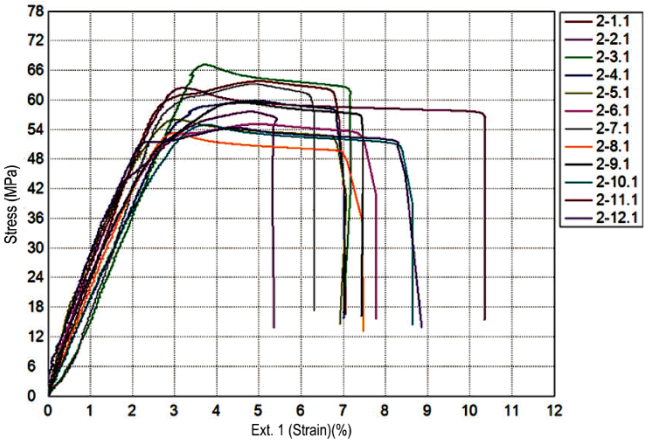


Figure 12 Tensile stress – strain diagram for all DoE runs

3.1 Statistical Analysis of Tensile Strength Property

Results of ANOVA for tensile strength testing are shown in Tab. 4. Based on regression analysis, mathematical model of the response surface (2FI – linear with 2 factor interaction) for tensile strength (TS) can be presented in the form of an Eq. (1), where all of the factors are in coded form which is shown also in Tab. 4.

Table 4 ANOVA for tensile strength testing (2FI model, DoF – degree of freedom)

Source	Sum of squares	DoF	Mean square	*F*-value	*p*-value	Remark
Model	207,15	3	69,05	14,37	0,0014	Significant
A – Layer height	148,60	1	148,60	30,93	0,0005	Significant
B – Infill density	0,0486	1	0,0486	0,0101	0,9224	
AB	31,13	1	31,13	6,48	0,0344	Significant
Residual	38,44	8	4,80			
Lack of fit	17,91	5	3,58	0,5236	0,7540	Not significant
Pure error	20,53	3	6,84			
Corrected total	245,59	11				

Tensile strength dependence on layer height and infill density can be presented in coded equation:

$$EB = 60{,}63 - 4{,}16 \cdot A - 0{,}0753 \cdot B + 2{,}17 \cdot A \cdot B. \quad (1)$$

By observing the Tab. 4 it is visible that the model is significant, which means that the appropriate statistical model is selected and that the model is accurately predicting the tensile strength in the model space. Lack of fit is not significant relative to the pure error which also gives the information that the model is satisfactory inside model parameter space. By increasing the layer height tensile strength is reduced because the A coefficient in the coded Eq. (1) is negative and from ANOVA, *A* coefficient is significant. Also, interaction of layer height and infill density is significant, which positively influences on tensile strength. Tensile strength response surface is shown in Fig. 13.

Influence of infill density and layer height on tensile strength is shown in Fig. 14

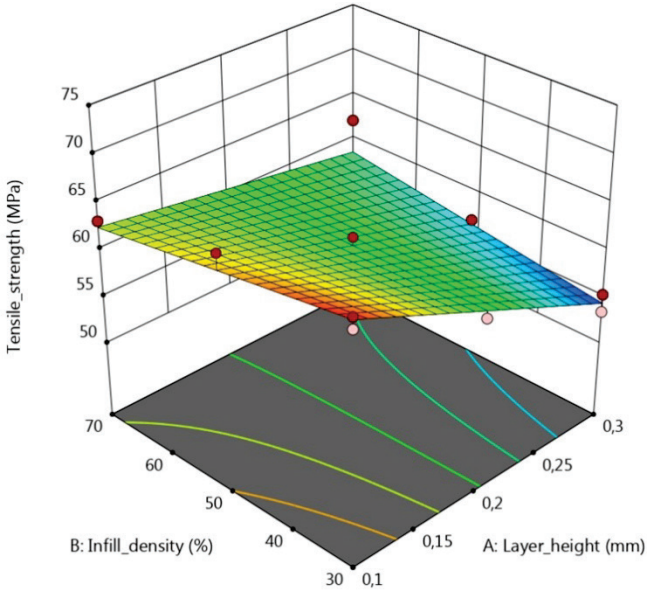


Figure 13 Tensile strength response surface

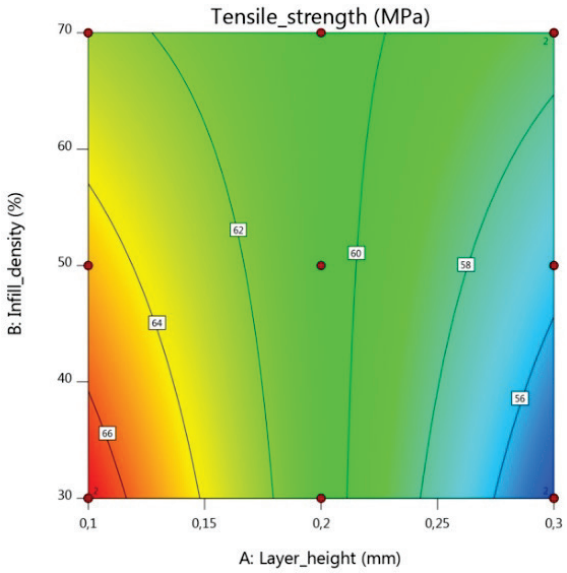


Figure 14. Influence of infill density and layer height on tensile strength

As it can be seen from Fig. 14, the most significant factor on tensile strength is layer height, where maximum tensile strength can be obtained with minimum layer height. Smaller layer height means that better inter-layer bonding can be accomplished and the result is increasing of tensile strength of the specimens. Although infill density is not significant factor, it contributes through interaction with layer height with positive influence.

3.2 Statistical Analysis of Elongation at Break

Results of ANOVA for elongation at break testing are shown in Tab. 5. Based on regression analysis, mathematical model of the response surface (2FI) for elongation at break (EB) can be presented in the form of an Eq. (2), where all of the factors are in coded form which is shown also in Tab. 5.

Table 5 ANOVA for elongation at break testing (2FI model, DoF – degree of freedom)

Source	Sum of squares	DoF	Mean square	*F*-value	*p*-value	Remark
Model	11,16	3	3,72	4,95	0,0394	Significant
A – Layer height	1,35	1	1,35	1,80	0,2162	
B – Infill density	5,32	1	5,32	7,07	0,0288	Significant
A·B	7,26	1	7,26	9,66	0,0145	Significant
Residual	6,01	8	0,7514			
Lack of fit	4,62	5	0,9242	1,99	0,3023	Not significant
Pure error	1,39	3	0,4633			
Corrected total	17,17	11				

Elongation at break coded equation:

$$EB = 7{,}54 - 0{,}3977 \cdot A + 0{,}7877 \cdot B + 1{,}05 \cdot A \cdot B. \quad (2)$$

By observing the Tab. 5 it is visible that the model is significant, which means that the appropriate statistical model is selected and that the model is accurately predicting the elongation at break in the model space. Lack of fit is not significant relative to the pure error which also gives the information that the model is satisfactory inside model parameter space. From ANOVA analysis it can be concluded that significant factor in this case is infill density, and interaction between infill density and layer height.

By increasing the infill density, elongation at break is also increased, while interaction between both parameters has opposite influence on elongation at break. Elongation at break response surface is shown in Fig. 15.

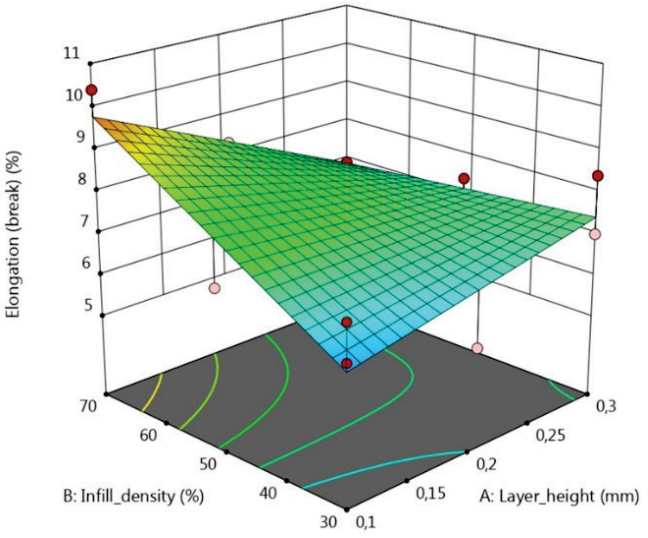


Figure 15 Elongation at break response surface

Influence of infill density and layer thickness on elongation at break is shown in Fig. 16.

In case of influence of infill density on elongation at break, it can be concluded, that with lower density, more brittle break will be present. In both cases, there more complex influence is present through interaction between both parameters, which is especially obvious in case of

elongation at break, where interaction is the most significant factor with positive influence on elongation at break (Eq. (2)).

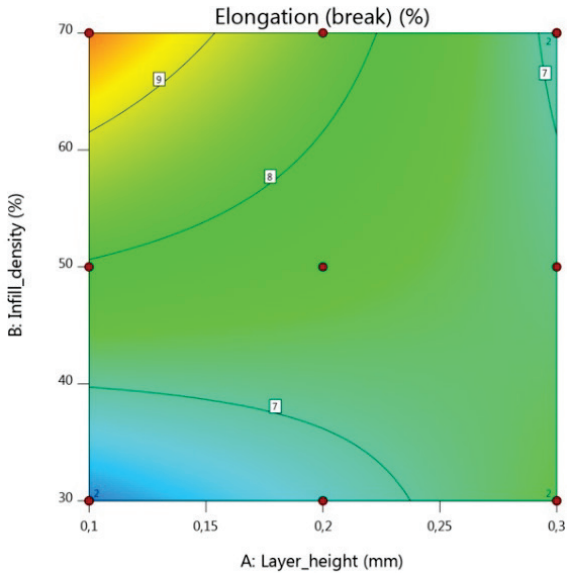


Figure 16 Influence of infill density and layer height on elongation at break

Unexpected result in this research is that infill density has almost no influence on tensile strength, or even negative influence in case of minimum layer height. Therefore this behaviour of specimens produced from recycled PLA has to be more investigated.

4 CONCLUSION

In this research DoE approach was utilised in order to assess suitability of recycled PLA filament usage in low-budget fused filament forming processes. Results have shown that the models are significant, and in correlation with already done research. Due to particle shape and size variation in shredded PLA material, low-budget filament extruders are not yet suitable for general use, so filament recycling is still not available to most of the users which use low-budget fused filament forming 3D printers. Filament produced on industrial grade extruder from virgin PLA material has satisfactory geometrical and mechanical properties, and can be used on low-budget FFF printers without any issues during printing, while filament produced from recycled PLA material has increased diameter variation which can lead to potential clogging during printing on low-budget FFF machines. The industry of filament recycling has great potential and is yet to be more explored especially in areas of filament dimensional stability and mechanical properties repeatability. Potential establishment of distributed centres for 3D printing waste material recycling is very promising and is yet to be adopted by industry worldwide.

Acknowledgements

This paper is part of the research included in project Increasing Excellence on Advanced Additive Manufacturing. This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 810708. The authors would like to thank the EU for the financing of the project and Lehrstuhl KV at Montanuniversity in Leoben for support in filament production.

Notice

The paper was presented at MOTSP 2021 – 12th International Conference Management of Technology – Step to Sustainable Production, which took place in Poreč/Porenzo, Istria (Croatia), on September 8–10, 2021. The paper will not be published anywhere else.

5 REFERENCES

[1] Gebler, M., Schoot Uiterkamp, A. J. M., & Visser, C. (2014). A global sustainability perspective on 3D printing technologies. *Energy Policy, 74*, 158-167. https://doi.org/10.1016/j.enpol.2014.08.033

[2] Diegel, O., Nordin, A., & Motte, D. (2020). *A Practical Guide to Design for Additive Manufacturing*. Springer Series in Advanced Manufacturing. Springer, 246 p. https://doi.org/10.1007/978-981-13-8281-9

[3] Beltrán, F. R., et al. (2021). Technical evaluation of mechanical recycling of PLA 3D printing wastes. *Polymers (Basel), 13*(8). https://doi.org/10.3390/polym13081247

[4] Hong, J. H., Yu, T., Park, S. J., & Kim, Y. H. (2020). Repetitive recycling of 3D printing PLA filament as renewable resources on mechanical and thermal loads. *Int. J. Mod. Phys. B, 34*(22-24), 1-5. https://doi.org/10.1142/S0217979220401475

[5] Ngo, T. D., Kashani, A., Imbalzano, G., Nguyen, K. T. Q., & Hui, D. (2018). Additive manufacturing (3D printing): A review of materials, methods, applications and challenges. *Compos. Part B Eng., 143*, 172-196. https://doi.org/10.1016/j.compositesb.2018.02.012

[6] Madhavan Nampoothiri, K., Nair, N. R., & John, R. P. (2010). An overview of the recent developments in polylactide (PLA) research. *Bioresour. Technol., 101*(22), 8493-8501. https://doi.org/10.1016/j.biortech.2010.05.092

[7] Baechler, C., Devuono, M., & Pearce, J. M. (2013). Distributed recycling of waste polymer into RepRap feedstock. *Rapid Prototyp. J., 19*(2), 118-125. https://doi.org/10.1108/13552541311302978

[8] Muñoz, V., Martínez, L., Carrasco-Gallego, R., de Juanes Marquez, J. & Hidalgo-Carvajal, D. (2020). Evaluation of the Circularity of Recycled PLA Filaments for 3D Printers. *Applied Sciences, 10*(24), 8967. https://doi.org/10.3390/app10248967

[9] Chiu, H. T., Huang, J. K., Kuo, M. T., & Huang, J. H. (2018). Characterisation of PC/ABS blend during 20 reprocessing cycles and subsequent functionality recovery by virgin additives. *J. Polym. Res., 25*(5). https://doi.org/10.1007/s10965-018-1522-6

[10] Babagowda, Kadadevara Math, R. S., Goutham, R., & Srinivas Prasad, K. R. (2018). Study of Effects on Mechanical Properties of PLA Filament which is blended with Recycled PLA Materials. *IOP Conf. Ser. Mater. Sci. Eng., 310*(1). https://doi.org/10.1088/1757-899X/310/1/012103

[11] Cruz Sanchez, F. A., Boudaoud, H., Hoppe, S., & Camargo, M. (2017). Polymer recycling in an open-source additive manufacturing context: Mechanical issues. *Addit. Manuf., 17*, 87-105. https://doi.org/10.1016/j.addma.2017.05.013

[12] Lanzotti, A., Martorelli, M., & Staiano, G. (2015). Understanding Process Parameter Effects of RepRap Open-Source Three-Dimensional Printers through a Design of Experiments Approach. *J. Manuf. Sci. Eng. Trans. ASME, 137*(1), 1-8. https://doi.org/10.1115/1.4029045

Authors' contacts:

Tomislav Breški, mag. ing. mech.
University of Zagreb,
Faculty of Mechanical Engineering and Naval Architecture,
Ivana Lucica 5, 10000 Zagreb, Croatia
+38516168338, tomislav.breski@fsb.hr

Lukas Hentschel, dipl. ing.
Montanuniveristät Leoben,
Chair of Polymer Processing,
Otto Glöckel-Straße 2, 8700 Leoben, Austria
+4338424023506, lukas.hentschel@unileoben.ac.at

Damir Godec, prof. dr. sc., dipl. Ing.
(Corresponding author)
University of Zagreb,
Faculty of Mechanical Engineering and Naval Architecture,
Ivana Lucica 5, 10000 Zagreb, Croatia
+38516168192, damir.godec@fsb.hr

Ivica Đuretek, Dr. mont., dipl. ing.
Montanuniveristät Leoben,
Chair of Polymer Processing,
Otto Glöckel-Straße 2, 8700 Leoben, Austria
+4338424023518, Ivica.Duretek@unileoben.ac.at

ISSN 1846-6168 (Print), ISSN 1848-5588 (Online)
https://doi.org/10.31803/tg-20210824184058

Original scientific paper

Single-Tray VLM vs Dual-Tray VLM: Quantitative Throughput Comparison

Goran Đukić*, Tihomir Opetuk, Brigita Gajšek, Tone Lerher

Abstract: In this paper quantitative comparison of resulting throughputs for single-tray and dual-tray VLM devices is presented. Comparison is based on mathematical models for throughput approximating dual command times of VLM's crane, for selected parameters of VLM device (height and crane's velocity) and selected picking times per delivered tray. Analysis showed that throughput increase achieved by using dual-tray VLM's depends mostly on the average picking time relative to the expected dual command time of the VLM's crane. Highest improvements are possible for picking time equal to expected dual command time and amounts over 80%, however for extremely low or high picking times improvements are significantly reduced.

Keywords: dual-tray VLM; order-picking; single-tray VLM; throughput model; vertical lift module systems

1 INTRODUCTION

Automated storage and retrieval systems (AS/RSs) are often implemented in logistics and manufacturing systems. We distinguish between several AS/RSs that enable storing and retrieving logistics units (loads) differing in dimensions and masses. Compared to non-automated systems, the use of AS / RS has a number of advantages, like reduction of labour costs, reduction of required space, increased reliability, accuracy, safety and security. There are also disadvantages higher investments costs and less flexibility [1]. Several different types of automated storage/retrieval systems have found their application in order-picking process, mainly due to the principle of bringing parts to human picker (making them so called parts-to-picker systems).

Process of order-picking is known as usually very laborious, with up to 55% of warehouse operating costs [2] or about 65% of logistics centre operating costs [3]. Therefore, it is understandable why many companies seek to improve order-picking with implementations of more efficient systems. The improvements are the most commonly built on reducing the time required to walk between the storage locations of ordered items, which often represents half of the time required to prepare a customer order [2]. Among all the types, part-to-picker AS/RSs allow the greatest reduction in travel time. Their main advantage is that the picker does not move along the storage racks. Instead of walking, the system delivers required items to the operator, to the area of his/her standing. Besides the name part-to picker, those systems are also found with names stock-to-operator, goods-to-man or end-of-aisle system.

An example of part-to-picker AS/RS is Vertical Lift Module (VLM). In VLM, the insertion/extraction (I/E) device is moving vertically and on its way extracts trays or totes from the shelves and delivers them to the operator) [4, 5]. Trays or totes are deposited on the pick shelf (or pick window) in front of the operator, colored red in Fig. 1. Usual VLM systems have only one picking place, one extractor and one lift (and are named single-tray VLM or single bay VLM). Producers of VLMs provide also various extended solutions, like dual-tray VLM, double extractor VLM, buffer VLM and double lift VLM. All those extensions are aimed to increase throughput (a.k.a. increased picking productivity) by reducing the system's cycle time. However, how much improvement would be expected using some advanced device instead of basic single-tray VLM configuration is not so simple to answer. It would be wrong and naive to simply assume that dual-tray or dual-lift might achieve doubled throughput compared with single-tray single-lift VLM. This paper focuses on dual-tray VLM and its throughput. Additionally, throughputs of dual-tray and single-tray VLMs are compared. The main idea is to search for picking productivity differences based on various parameters. The aim is to investigate the degree of efficiency increase of a dual-tray VLM in relation to a single-tray VLM, based on a developed analytical models of the analysed devices and corresponding processes. Overall, such analysis contributes to the logistics engineering field, both from the scientific and the managerial aspect.

Figure 1 Vertical Lift Module (VLM)

The paper is several main chapters. Chapter 2 presents a brief review of research papers regarding VLM throughput models (developing and usage). Chapter 3 reviews with more details two used throughput models, namely single-tray VLM throughput model from Meller & Klote, 2004 [6] and

dual-tray VLM throughput model from Dukic et al., 2015 [7]. Chapter 4 presents details of the conducted analysis and results. Paper ends with the conclusions and further research directions.

2 BACKGROUND AND LITERATURE REVIEW

Up to the last several years, literature about VLMs was relatively scarce, although those systems have been in use for almost 50 years [4]. Apart from some papers discussing applications, main parts and benefits of using VLMs [4, 5], the first paper that presented throughput model of single-tray VLM was by Meller & Klote, 2004 [6]. Model from this paper is used for analysis in this paper, so details are explained in sub-chapter 3.1. As single-tray VLM was supplemented by dual-tray VLM (also named dual bay VLM, dual delivery configuration VLM, or VLM with double access handling option), a demand for a throughput model arose to aid the warehouse designers and managers to determine expected throughput. Considering mini-load AS/RS models [8-10] and single-tray VLM model [6] previously presented in literature, dual-tray VLM throughput model was developed and presented by Dukic et al., 2015 [7]. Accuracy of analytical model was determined by comparing results to the results obtained by simulation. The proposed model confirmed satisfactory accuracy for estimating throughput of system with single dual-tray VLM and human order-picker. The model assumed random storage policy without using batching or retrieval sequencing.

Several more papers dealing with both single- and dual-tray VLMs were published afterwards. Battini et al. [11] performed case study, considering different storage assignment policies and batch retrievals. Rosi et al. [12] analysed VLMs using simulation model, considering various velocity profiles of lifts. Lenoble et al., [13] analysed order batching optimization in single-tray VLMs, confirming that batching increases throughput. Dukic et al. [14] used single-tray VLM model for cycle-time and ergonomic assessment. Sgarbossa et al. [15] analysed class-based storage and sequencing retrievals to increase throughput of dual-tray VLMs with short picking times. Same authors were dealing with economic evaluation of VLM's application in [16], developing cost model for dual-tray VLM. Dukic et al. [17] analysed influence of pick-time distribution on expected throughput of dual-tray VLMs. Lastly, Vanhauwermeiren et al. [18] presented throughput models for double extractor VLM, buffer VLM and double lift VLM, providing some insights into throughput differences of additional various types of VLM devices.

In this paper, authors also compared resulted throughput of all VLM types, varying only height of the units and picking time. The authors presented results in form of graphs, however lacking details and exact quantitative differences.

3 SINGLE-TRAY AND DUAL-TRAY VLM THROUGHPUT MODELS

In this chapter single-tray VLM and dual-tray VLM throughput models are presented. Although published with explanations in original papers, the presentation is repeated in some parts to show the models more clearly and adjusted for comparison analysis.

3.1 Single-Tray VLM Throughput Model

Single-tray VLM model was presented in [7]. Model assumed system of one VLM device and one human picker. VLM is with one pick location, from which picker is picking items from delivered trays (or could be totes). Those trays are delivered by I/E device (called crane in the text below). Model originally calculated total throughput time to complete a set of orders with n items, which is actually the sum of the expected retrieval time (crane) and picking time (human), considering that storages and retrievals are always performed in a combination as dual command cycle, except the first and the last operations which are performed as single command cycles. Also model calculated expected number of trays to be delivered based on number of picking items and number of trays device. In this paper we assumed work of VLM with only dual commands, in order to calculate throughput of the single-tray VLM and human picker expressed in number of delivered trays per hour. Therefore, picking time is expressed by average pick time per tray, not per picked item, avoiding calculation of expected items per delivered tray. In other words, no batching or picking sequencing is assumed. Expected dual command cycles is calculated based of expected travel between picking position and sections within VLM (h_1, h_2, h_3) and velocity of the crane v, as illustrated in Fig. 2.

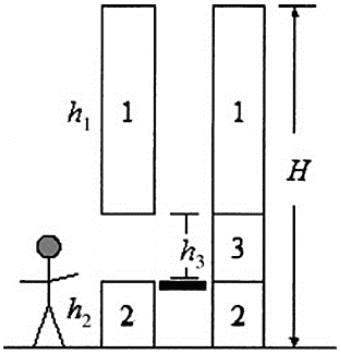


Figure 2 Side view of VLM with typical sections [7]

Assuming random storage, model first calculates expected travel times from/to picking place and sections (t_{0i}) and expected travel times between sections (t_{ij}). Expected dual-command VLM crane travel time $E(DC)$ is then calculated based on probabilities of a storage/retrieval of a tray in corresponding sector (p_1, p_2, p_3) as a basis to calculate probabilities that dual command cycle stores a tray in section i and retrieves a tray in section j(p_{ij}). According to the 4 pickups and deposits and three delay times due to acceleration and deceleration, there is an additional constant time per cycle (C). As said, expected system cycle time $E(CT)$ is then simply a sum of expected dual command cycle time and picking time.

Model is given below. For more detailed explanation readers are referred to [7] and [11].

$$
\begin{aligned}
t_{01} &= \left(h_3 + h_1/2\right)/v \\
t_{02} &= \left(h_2/2\right)/v \\
t_{03} &= \left(h_3/2\right)/v
\end{aligned} \tag{1}
$$

$$
\begin{aligned}
t_{11} &= \left(h_1/3\right)/v \\
t_{12} &= t_{21} = \left(h_1/2 + h_3 + h_2/2\right)/v \\
t_{13} &= t_{31} = \left(h_1/2 + h_2/2\right)/v \\
t_{22} &= \left(h_2/3\right)/v \\
t_{23} &= t_{32} = \left(h_2/2 + h_3/2\right)/v \\
t_{33} &= \left(h_3/3\right)/v
\end{aligned} \tag{2}
$$

$$
\begin{aligned}
p_1 &= 2h_1/\left(2H - h_3\right) \\
p_2 &= 2h_2/\left(2H - h_3\right) \\
p_3 &= h_3/\left(2H - h_3\right)
\end{aligned} \tag{3}
$$

$$
E(DC) = \sum_{i=1}^{3}\sum_{j=1}^{3}(t_{0i} + t_{ij} + t_{0j}) \cdot p_i p_j \tag{4}
$$

$$
C = 3 \cdot t_{\mathrm{a/d}} + 4 \cdot t_{\mathrm{p/d}} \tag{5}
$$

$$
E(CT) = E(DC) + C + p_{\mathrm{T}} \tag{6}
$$

3.2 Dual-Tray VLM Throughput Model

Dual-tray VLM model presented in [11] assumed system of single VLM with two picking locations (two locations for delivered trays). With 2 picking position, VLM crane is able to store previous tray and retrieve next tray from the rack location while human picker is picking item(s) from another place. Storage and retrieval of trays are still done with dual commands, however now alternatively form those 2 mentioned locations, positions A and B, which is illustrated together with sections of VLM device in Fig. 3. The throughput model in this case is based on system's cycle similar to mini-load AS/RS model developed by Bozer and White [8-10], but using idea of calculation crane's expected dual-command of VLM presented in section 3.1. Since crane is doing alternatively dual commands from two positions, first average $E(DC)$ is calculated from those 2 expected dual-commands and time to move between them (which again were calculated based on travel times between picking places and sections ($t_{\mathrm{A}j}$, $t_{\mathrm{B}j}$). Travel time between sections and probabilities are the same as for single-tray VLM model. Standard deviation of dual command travel time was approximated as $S(DC) \approx 0.383 \cdot E(DC)$, based on calculation for various configurations, leading to the limits of uniform distribution of approximated dual command travel time (k_1 and k_2) and limits of uniform distribution of dual command cycle time (t_1 and t_2). Please note that in this case constant time per cycle C consists of four times to pickup/deposit a tray and four acc./dec. delay times.

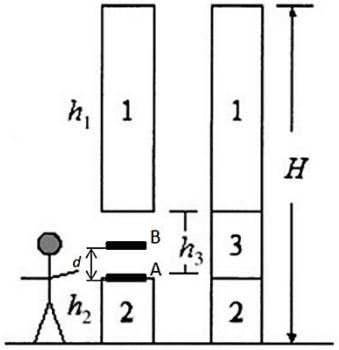


Figure 3 side view of dual-tray VLM with typical sections [7]

Then, based on assumption that pick time is deterministic or exponentially distributed, expected system cycle time $E(CT)$ could be calculated in two variations.

This model is given below, while for more detailed explanation readers are also referred to paper [11].

$$
E(DC) = \frac{E(DC)_{\mathrm{A}} + E(DC)_{\mathrm{B}}}{2} + \frac{d}{v} \tag{7}
$$

$$
\begin{aligned}
E(DC)_{\mathrm{A}} &= \sum_{i=1}^{3}\sum_{j=1}^{3}(t_{\mathrm{A}i} + t_{ij} + t_{\mathrm{A}j}) \cdot p_i p_j \\
E(DC)_{\mathrm{B}} &= \sum_{i=1}^{3}\sum_{j=1}^{3}(t_{\mathrm{B}i} + t_{ij} + t_{\mathrm{B}j}) \cdot p_i p_j
\end{aligned} \tag{8}
$$

$$
\begin{aligned}
t_{\mathrm{B1}} &= \left(h_3 - d + h_1/2\right)/v \\
t_{\mathrm{B2}} &= \left(d + h_2/2\right)/v \\
t_{\mathrm{B3}} &= \left[\left((h_3 - d)/2\right) \cdot \left((h_3 - d)/h_3\right) + \left(d/2\right) \cdot \left(d/h_3\right)\right]/v = \\
&= \left[\left((h_3 - d)^2 + d^2\right)/2h_3\right]/v
\end{aligned} \tag{9}
$$

$$
\begin{aligned}
k_1 &= E(DC) - 1.7321 \cdot S(DC) \\
k_2 &= E(DC) + 1.7321 \cdot S(DC)
\end{aligned} \tag{10}
$$

$$
\begin{aligned}
t_1 &= k_1 + C \\
t_2 &= k_2 + C
\end{aligned} \tag{11}
$$

$$
E(CT) = \begin{cases} E(DC) + C & \text{for } 0 < p_{\mathrm{T}} \le t_1 \\ \dfrac{p_{\mathrm{T}}^2 - 2p_{\mathrm{T}}t_1 + t_2^2}{2(t_2 - t_1)} & \text{for } t_1 < p_{\mathrm{T}} \le t_2 \\ p_{\mathrm{T}} & \text{for } t_2 < p_{\mathrm{T}} \end{cases} \tag{12}
$$

$$
\begin{aligned}
E(CT) &= E(DC) + C + \\
&+ \frac{p_{\mathrm{T}}^2}{t_2 - t_1}\left[exp\left(-\frac{t_1}{p_{\mathrm{T}}}\right) - exp\left(-\frac{t_2}{p_{\mathrm{T}}}\right)\right]
\end{aligned} \tag{13}
$$

4 RESULTS OF THROUGHPUT COMPARISON

With presented models for single-tray VLM and dual-tray VLM, one can for same input parameters (VLM's height, dimensions of sections, crane velocity, acceleration/deceleration delay time, pickup/deposit delay time, pick time per delivered tray) compare resulting system's cycle time and therefore throughput in delivered trays per hour RT as

$$q = 3600/E(CT) \tag{14}$$

Comparison was done for plenty combinations of systems. For four various VLM heights and three different speeds of lift, there were total 12 different VLM configurations used in research (dimensions of section h_2 = 900 mm, h_3 = 750 mm and d = 300 mm were constant in all analysed configurations). For each configuration throughputs were calculated for five different values of average pick times per delivered tray. In first step, three pick time values were specifically selected to be approximately equal to the lower value of approximated uniform distribution of dual-command cycle time of VLM's crane mean (average) dual-command cycle time and upper value of approximated uniform distribution of dual-command cycle time of VLM's crane, respectively, named p_{T1}, p_{T2} and p_{T3}. In next step of the research two other picking times were selected to be relatively small and high, named p_{T0} and p_{T4}, defined as

$$\begin{aligned} p_{T0} &= p_{T1}/2 \\ p_{T4} &= 2 \cdot p_{T3} \end{aligned} \tag{15}$$

Tab. 1 presents values of first three selected picking times for analysed 12 configurations

Table 1 Picking times per tray, in seconds

H (mm)	v (cm/s)								
	50			100			150		
	p_{T1}	p_{T2}	p_{T3}	p_{T1}	p_{T2}	p_{T3}	p_{T1}	p_{T2}	p_{T3}
4500	27	34	41	25	29	33	25	27,5	30
6000	28	37,5	47	26	31	36	25	28,5	32
7500	29	41,5	54	26	32,5	39	25	29,5	34
9000	31	45,5	60	27	34,5	42	26	31	36

Based on models presented above, resulting throughputs are given in Tab. 2 and Tab. 3.

Comparison of achieved throughputs, expressed in percentage of increased throughput by using dual-tray VLM, is given in Tab. 4.

Table 2 Single-tray VLM's throughput (delivered trays per hour)

H (mm)	v (cm/s)								
	50			100			150		
	q_1	q_2	q_3	q_1	q_2	q_3	q_1	q_2	q_3
4500	61,43	54,88	49,59	69,50	64,52	60,20	71,71	68,31	65,22
6000	56,76	49,36	43,67	65,79	60,28	55,62	69,93	65,48	61,56
7500	52,69	44,54	38,57	63,53	56,99	51,67	68,21	62,85	58,27
9000	48,48	40,56	34,86	60,37	53,63	48,24	65,35	59,91	55,31

Table 3 Dual-tray VLM's throughput (delivered trays per hour)

H (mm)	v (cm/s)								
	50			100			150		
	q_1	q_2	q_3	q_1	q_2	q_3	q_1	q_2	q_3
4500	106,26	101,12	87,80	124,40	120,81	109,09	131,92	128,80	116,13
6000	95,64	90,36	76,60	116,81	112,32	100,00	126,09	122,95	112,50
7500	86,75	81,08	80,00	109,92	105,63	92,31	120,68	117,49	105,88
9000	79,30	73,65	60,00	103,75	99,12	85,71	115,64	111,77	100,00

Table 4 Increased throughput of dual-tray VLMs compared with single-tray VLMs

H (mm)	v (cm/s)								
	50			100			150		
	p_{T1}	p_{T2}	p_{T3}	p_{T1}	p_{T2}	p_{T3}	p_{T1}	p_{T2}	p_{T3}
4500	72,96%	84,27%	77,07%	78,99%	87,25%	81,21%	83,95%	88,55%	84,00%
6000	68,52%	83,06%	75,38%	77,55%	86,33%	79,78%	80,32%	87,77%	82,75%
7500	64,65%	82,05%	72,83%	73,04%	85,36%	78,64%	76,94%	86,95%	81,71%
9000	63,57%	81,59%	72,10%	71,84%	84,83%	77,69%	76,97%	86,56%	80,81%

Visualizing results of throughput of one selected configuration (in this case H = 6000 mm, v = 100 cm/s) with Fig. 4 clearly shows that resulting throughput is higher for smaller picking times, but also that difference is variable (in our cases between 63,57% and 88,55%).

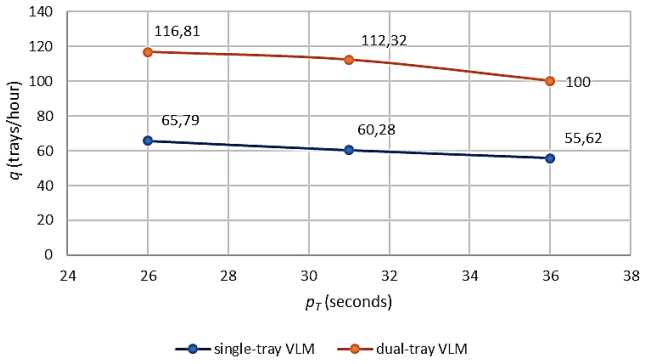


Figure 4 Throughput's of single-tray and dual-tray VLMs depending on picking time per delivered tray (three analysed picking times)

From the Tab. 4 one can conclude that largest increase of throughput by using dual-tray instead of single-tray VLM is possible in cases where picking time per tray equals mean (average) dual-command cycle time of VLM's crane. However, question arises whether curves will continue on both sides for lower and higher throughputs with the same tendencies, which the reason for analysis of throughputs for p_{T0} and p_{T4} is picking times.

Table 5 Increased throughput of dual-tray VLMs compared with single-tray VLMs including 2 additional extreme picking times

H (mm)	v (cm/s)														
	50					100					150				
	P_{T0}	P_{T1}	P_{T2}	P_{T3}	P_{T4}	P_{T0}	P_{T1}	P_{T2}	P_{T3}	P_{T4}	P_{T0}	P_{T1}	P_{T2}	P_{T3}	P_{T4}
4500	33	73	84	77	39	36	79	87	81	41	38	84	89	84	42
6000	31	69	83	75	38	35	78	86	80	40	37	80	88	83	41
7500	30	65	82	73	36	33	73	85	79	39	35	77	87	82	41
9000	29	64	82	72	36	33	72	85	78	39	35	77	87	81	40

Tab. 5 is now showing extended Tab. 4, with percentages of increased throughput including those two extreme picking times. In this case it is very interesting to see how the potential of using dual-tray VLM compared to single-tray

VLM is heavily reduced in cases of picking times significantly lower or higher than lower and upper value of approximated uniform distribution, respectively, as shown in Fig. 5 for one selected configuration.

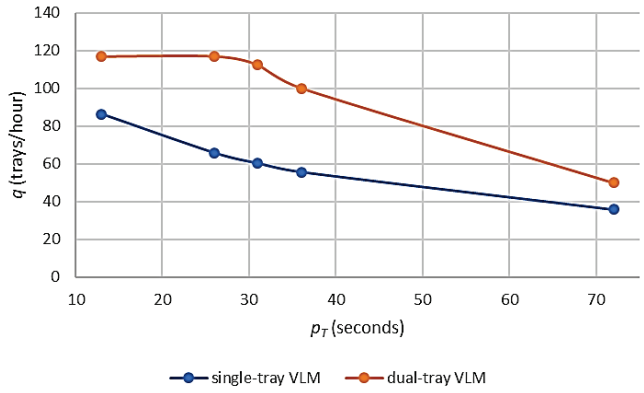


Figure 5 Throughput's of single-tray and dual-tray VLMs depending on picking time per delivered tray (all analysed picking times)

5 CONCLUSIONS

VLM systems are evolving intensively, which raises their importance among AS/RSs. Development is taking place in the direction of new possibilities of process use, capacity improvement, improved productivity and rational use of space. Importance is also given to the health of workers in terms of ergonomics. The system's throughput calculation is used to achieve the desired performance indicators through the selection of the optimal type of VLM system. Research has shown advantages of the dual-tray VLM system in comparison to the single-tray VLM system. The dual-tray VLM system does not wait for the order-picker to complete picking items from the delivered tote but already delivers the next tote in the meantime. Comparison of throughputs of mentioned systems revealed that installing a dual-tray VLM system could benefit in up to 90% higher throughput than the single-tray VLM systems. However, the performance of dual-tray VLM system relative to the performance of dingle-tray decreases for average picking times lower and higher than the mean dual command cycle time of lift. Calculations done for two arbitrary chosen picking times extraordinary different that (2 times less and 2 times higher than lower and upper values of uniformly distributed dual command cycle time) showed that in those cases performances of dual-tray VLMs were just 30 to 40% better compared to the single-tray VLMs. The calculation revealed that actual time spent for picking from delivered tray influences absolute throughput and relative difference of throughputs achieved by VLM systems as well. The calculated result can be beneficially used by warehouse designers and managers when deciding on the VLM system type.

In the future it would be interesting to check how much efficiency increase is possible to achieve by storage and/or batching methods implemented with dual-tray VLMs. It would be also interesting to investigate differences between dual-tray, double extractor and double lift VLMs, not only in expected throughputs but also in investment and operating costs.

Another direction of further research is related with the ergonomics. As already mentioned, paper [14] analysed single-tray VLM from the ergonomic aspect as well. Such analysis could be done for dual-tray VLM, revealing how much increased productivity increases energy expenditure of the picker, therefore affecting more fatigue.

Notice

The paper was presented at MOTSP 2021 – 12th International Conference Management of Technology – Step to Sustainable Production, which took place in Poreč/Porenzo, Istria (Croatia), on September 8–10, 2021. The paper will not be published anywhere else.

6 REFERENCES

[1] Roodbergen, K. J. & Iris, F. A. V. (2009). A survey of literature on automated storage and retrieval systems. *European Journal of Operational Research, 194*, 343-362. https://doi.org/10.1016/j.ejor.2008.01.038

[2] Tompkins, J. A., White, J. A., Bozer, Y. A., Frazelle, E. H., Tanchoco, J. M. A., & Trevino, J. (2010). *Facilities Planning, 4th ed*. John Wiley & Sons, Inc.

[3] Coyle, J. J., Bardi, E. J., & Langley, C. J. (1996). *The Management of Business logistics*. West Publishing, St. Paul, MN

[4] Romaine, E. (2004). Dynamic Storage Systems MODULE 5.5 VERTICAL LIFT MODULES, *The Essentials of Material Handling: part 2 –The Basic Product Knowledge Program*. Material Handling Industry of America, Charlotte, North Carolina.

[5] See https://www.mhi.org/solutions-community/solutions-guide/vertical-lift

[6] Meller, R. D. & Klote, J. F. (2004). A throughput model for carousel/VLM pods. *IIE Transactions, 36*, 725-741. https://doi.org/10.1080/07408170490458472

[7] Dukic, G., Opetuk, T., & Lerher, T. (2015). A throughput model for a dual-tray Vertical Lift Module with a human order-picker, *International Journal of Production Economics, 170 (Part C)*, 874-881. https://doi.org/10.1016/j.ijpe.2015.04.009

[8] Bozer, Y. A. & White, J. A. (1984) Travel-time models for automated storage/retrieval systems. *IIE Transactions, 16*(4), 329-338. https://doi.org/10.1080/07408178408975252

[9] Bozer, Y. A. & White, J. A. (1990). Design and performance models for end-of-aisle order picking systems. *Management Science, 36*(7), 852-866. https://doi.org/10.1287/mnsc.36.7.852

[10] Bozer, Y. A. & White, J. A. (1996). A generalized design and performance analysis model for end-of-aisle order-picking systems. *IIE Transactions, 27*(1), 271-280. https://doi.org/10.1080/07408179608966275

[11] Battini, D., Calzavara, M., Persona, A. & Sgarbossa, F. (2016). Dual-tray Vertical Modules for Fast Order Picking. *14th IMHRC Proceedings*, Karlsruhe, Germany.

[12] Rosi, B., Grašić, L., Đukić, G., Opetuk, T., & Lerher, T. (2016). Simulation-Based Performance Analysis of Automated Single-Tray Vertical Lift Module. *International Journal of Simulation Modelling, 15*(1), 97-108. https://doi.org/10.2507/IJSIMM15(1)8.328

[13] Lenoble, N., Frein, Y., & Hammami, R. (2018). Order batching in an automated warehouse with several vertical lift modules: Optimization and experiments with real data. *European Journal of Operational research, 267*(3), 958-976.

https://doi.org/10.1016/j.ejor.2017.12.037
[14] Dukic, G., Rose, L., Gajsek, B., Opetuk T., & Cajner, H. (2018). Space, Time and Ergonomic Assessment of Order-Picking Using Vertical Lift Modules, ICIL *2018 Proceedings*, Ber Sheeva, Israel, 68-74.
[15] Sgarbossa, F., Calzavara, M., & Persona, A. (2019). Throughput models for a dual-tray VLM order picking system under different configurations. *Industrial Management & Data Systems, 119*(6), 1268-1288. https://doi.org/10.1108/IMDS-11-2018-0518
[16] Sgarbossa, F., Calzavara, M., & Persona, A. (2019). Vertical Lift Module for small items order picking: an economic evaluation. *International Journal of Production Economics 210*, 199-210. https://doi.org/10.1016/j.ijpe.2019.01.012
[17] Đukić, G., Opetuk, T., Cajner, H., & Gajšek, B. (2019). Influence of pick time distribution on expected throughput of dual-tray VLMs. *MHCL 2019 Proceedings*, University of Belgrade, Faculty of Mechanical Engineering, 271-274.
[18] Vanhauwermeiren, P., Juwet, M., & Versteyhe, M. (2020). Throughput Models for a Stand-Alone Vertical Lift Module. *International Journal of Industrial and Operations Research. 3*(005), 2-27. https://doi.org/10.35840/2633-8947/6505

Authors' contacts:

Goran Dukic, prof. dr. sc.
(Corresponding author)
University of Zagreb,
Faculty of Mechanical Engineering and Naval Architecture.
Ivana Lučića 5, 10000 Zagreb, Croatia
goran.dukic@fsb.hr

Tihomir Opetuk, assist. prof. dr. sc.
University of Zagreb,
Faculty of Mechanical Engineering and Naval Architecture,
Ivana Lučića 5, 10000 Zagreb, Croatia
tihomir.opetuk@fsb.hr

Brigita Gajšek, assoc. prof. dr. sc.
University of Maribor, Faculty of Logistics,
Mariborska cesta 7, 3000 Celje, Slovenia
brigita.gajsek@um.si

Tone Lerher, prof. dr. sc.
University of Maribor, Faculty of Logistics,
Mariborska cesta 7, 3000 Celje, Slovenia
tone.lerher@um.si

ISSN 1846-6168 (Print), ISSN 1848-5588 (Online)
https://doi.org/10.31803/tg-20210209111953

Preliminary communication

Comparative Study on the In-Ladle Treatment Techniques for Nodulizing the Iron's Graphite

Imre Kiss

Abstract: The objectives of this research is to study and understand the nodulizing of ductile iron using in-ladle treatment process. Among the more common nodulizing agents is magnesium (Mg) which is conventionally added to the cast iron by combining suitable alloys of one or both of these elements with molten cast iron. Depending on the characteristics of each master alloy used as nodulizer, different treatment methods and techniques are used, among these, the most widely used being in-ladle, in-mould, and flow-through, the first being the most used. This research deals with the parameters, that affect the quality of ductile iron produced using in-ladle treatment process. The parameters involved are the percentage of magnesium–ferrosilicon (Fe–Si–Mg) used and the nodulizing technique. In-ladle treatment used consists of a deep pocket into the bottom of ladle, in which magnesium–ferrosilicon is placed into it together with a steel scrap barrier (steel sheets) or calcium carbide. This study, take into account, the degree of assimilation of magnesium, which shows the performance of the chosen process, depending on the nodulizer used and the temperature of the treatment.

Keywords: assimilation degrees of magnesium; ductile iron (nodular graphite iron); in-ladle treatment methods; magnesium; nodulizing agents; silicon-based master alloys

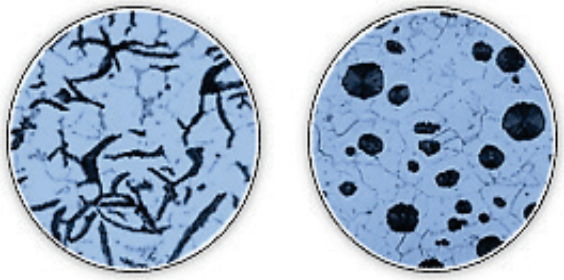
1 INTRODUCTION

Ductile iron (nodular graphite iron) has became one of the most important engineering materials, in view of its excellent castability, significantly better mechanical properties and low cost [1-6]. Generally, ductile cast iron consist of graphite spheroids dispersed in a matrix. The ductile iron can be produced by adding small quantities of magnesium [Mg] to a base cast iron which transforms graphite spheroids instead of flakes [3-13]. Therefore, production of nodular cast iron consists of three basic stages [1-13]:

- Casting of basic cast iron with proper chemical composition, characterised by the high graphitization (nodulizing) ability. This is insured by appropriate high content of carbon and silicon. The cast iron cannot contain elements opposing the crystallization of nodular graphite (the antispheroidizing elements) in amounts exceeding the determined limits;
- Introducing the spheroidizing (nodulizing) agent into the molten metal, most often magnesium or its carriers in the form of various alloys being used for this purpose;
- Subjecting the cast iron to graphitizing (nodulizing), modification directly after the spheroidizing (nodulizing), with ferrosilicon or calcium silicon with small additions of other elements.

The carbon present in molten iron is normally in flake form, and if the metal solidifies with the carbon in such form [1–3]. For a number of years it has been known that flake graphite can be converted to the nodular form by the use of nodulizing agents, which initially were used to treat gray iron as it flowed from the melting furnance or when it was received in the ladle from which castings were poured [1, 4].

Nodulization is a process of controlling the structure and properties by changing the graphite shape from flakes to spheroidal in cast iron during solidification [1-8]. The nodularisers are added in liquid iron to promote the formation of spheroidal or compacted form of graphite, specific for the ductile irons. Therefore, a certain quantity of magnesium is necessary to obtain the graphite in spheroidal or compacted form [1-13].



(a) (b)

Figure 1 Microstructure for Cast Iron (100×): (a) gray cast iron; (b) ductile iron

The properties of cast iron can be improved by the addition to it of nodulizing elements, commonly magnesium and cerium, or both [1-13]. In the presence of these elements the free graphite in cast iron tends to assume a spheroidal form, and both the tensile strength and ductility of the cast iron are increased. Nodulizing agents containing the nodulizing elements are added, suitably, by immersing them into the molten iron. Among the nodulizing agents which are immersed into iron are magnesium–ferrosilicon and cerium–containing magnesium–ferrosilicon [1, 3, 8, 11].

Nodularizing, or magnesium treatment, of cast iron is a method of modifying the solidification structure so that the graphite phase precipitates and grows as spherical particles instead of flakes, thus resulting in a ductile cast iron with significantly improved mechanical properties [1-13]. The nodularizing action can be described as desulfurizing and deoxidizing treatment, where elements having strong affinity to both sulfur and oxygen are added. This is done by adding a strong sulfide and oxide forming agents as magnesium. The less violent treatment will, for the best available processes, give low fume, smoke and slag formations, and consequently high magnesium recoveries [1, 4].

According to the prior art nodular cast iron may be produced by treating the molten cast iron with nodulizing agent so as to impart to the cast iron in the as–cast condition a minimum amount of the nodulizing agent [1-6]. Among the

more common nodulizing agents is magnesium which is conventionally added to the cast iron by combining suitable alloys of one or both of these elements with molten cast iron.

Figure 2 Silicon-based (light) pre-alloys used as nodulizer

The most commonly used as nodulizers are silicon–based light pre–alloys which contains spheroidal graphite forming elements such as magnesium, cerium, calcium, barium, etc. On the other hand, silicon which is the primary graphitising element, prevents carbide formation and controls the release of magnesium. Nodularisers are ferrosilicon alloys containing magnesium with, when needed, rare–earth elements [1-6]. In practice, the nodulariser usually contain magnesium, as pure magnesium, or as an alloy, such as magnesium–ferro–silicon (Fe–Si–Mg alloy) or nickel–magnesium (Ni–Mg alloy), which may contain rare earth metals (cerium, lantan), required in order to counteract the harmful effect of certain trace elements on the iron graphite shape (notably lead, antimony and bismuth). Magnesium is the main element in Fe–Si–Mg alloys responsible for creating the necessary conditions for the graphite phase to grow from the liquid into the required spheroidal form [1, 2]. The level of magnesium can be selected from a range between 5 to 10% [1-6]. For commercial production of ductile iron, these master alloys may contain additions of aluminum, calcium, or rare earths (cerium, lantan). Calcium is an element which retards the rate of reaction of magnesium with the liquid iron and thereby improves magnesium recovery and reduces the reaction's violence. In excessive amounts, Calcium [Ca] can produce slag [1, 2].

Nowadays, iron foundries supply varieties of ductile iron products, ranging from low quality to high quality. Several choice factors include treatment method used, degree of acceptable reactivity and economy of addition rate [4–13]. Many ways of introducing magnesium or magnesium containing master alloys into cast iron have been developed. Light master alloys require the use of appropriate methods for improving magnesium recovery by keeping the treatment alloy below the liquid iron surface until it is fully dissolved, thus minimizing magnesium losses and reducing pyroeffect [1, 12]. The decision of whether to use a nodulariser containing rare earth elements is generally determined by the quality and consistency of the raw materials used as melt stock. Depending on the characteristics of each master alloy used as nodulizer, different treatment methods and techniques are used, among these, the most widely used being in–ladle, in–mould, and flow–through, the first being the most used [1, 4, 7, 11, 12].

2 IN-LADLE TREATMENT METHODS

In-ladle nodulizing is one of the most common treatment technology used in today industries due to its simplicity [1-7, 12]. For in-ladle treatment, the magnesium–ferrosilicon is introduced into a pocket built into the ladle and is then covered with either steel punching or ferrosilicon. The cover acts as a physical barrier between the magnesium–ferrosilicon and the pouring molten cast iron which delays reaction time, prevents floating of magnesium–ferrosilicon [1, 13].

A number of in–ladle treatment techniques have been developed to prepare ductile iron over the years [1, 4, 12]. The most common treatment techniques in use today are the plunging process, the open ladle process, the sandwich process, and tundish process.

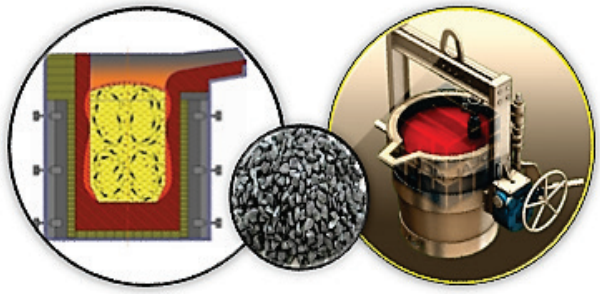


Figure 3 In-ladle treatment

As a way of increasing the assimilation of magnesium (Mg) from the pre–alloy, in order to achieve the nodularization of the graphite of cast iron, changes made constructively to the treatment ladle were used [1, 12, 13]. Thus have evolved the treatment procedures, from simply immersion with the plunging bell, to the treatment in a special pocket made in the bottom of the treatment ladle [1, 12, 13].

- The Plunging process (Fig. 4) is one of the most widely used for ductile iron production, which use a refractory plunger bell, containing pure magnesium or magnesium master alloys. This method is simple and widely used but magnesium recovery rates are inconsistent [1, 4, 9, 12]. Moreover it is necessary to use more nodulariser to successfully achieve the required level of treatment.
- The Open Ladle process (Fig. 5) is the choice of many foundries worldwide, due to simplicity and low investment costs [1, 4, 9, 12]. The nodulariser is added into the bottom of treatment ladle and the ladle is subsequently filled. The disadvantages of the process are excessive flame coupled with variable magnesium recoveries and inefficient use of the treatment alloy.
- The Sandwich (Overpouring) process (Fig. 6) is an improved modification of the open ladle process. In this process, the magnesium–ferrosilicon is introduced into pocket built into the ladle and is covered with steel scrap or ferrosilicon [1, 4, 9, 12]. The iron is then poured into the ladle and reaction with the treatment alloy is slowed by the steel scrap barrier (steel sheets). The major advantages of this method are simplicity and low cost.

The sandwich process is flexible and can be used for different sizes of ladles.

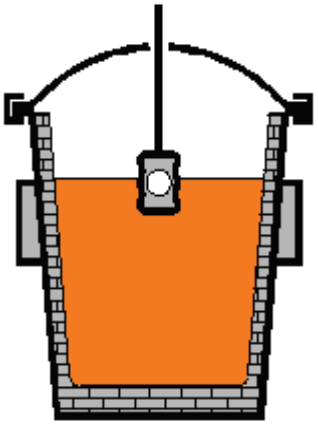


Figure 4 The Plunging process

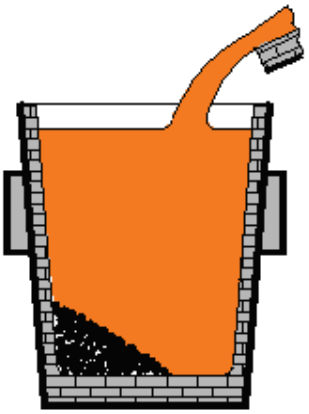


Figure 5 The Open Ladle process

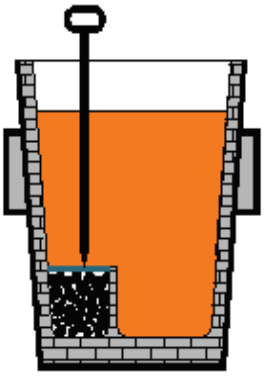


Figure 6 The Sandwich process

- The Trigger method (Fig. 7) is similar to the Sandwich method and uses the same treatment ladle with a "pocket", in which the nodulizer is placed, over which a layer of calcium carbide is placed, instead of steel sheets. The liquid iron causes a layer of slag over the nodulizing alloy, which prevents, for the time being, direct contact between cast iron and the nodulizer [1, 4, 9, 12]. After filling the treatment ladle, the slag layer is perforated with a steel bar, thus making contact between the iron and the nodulizer. The reaction is less violent.

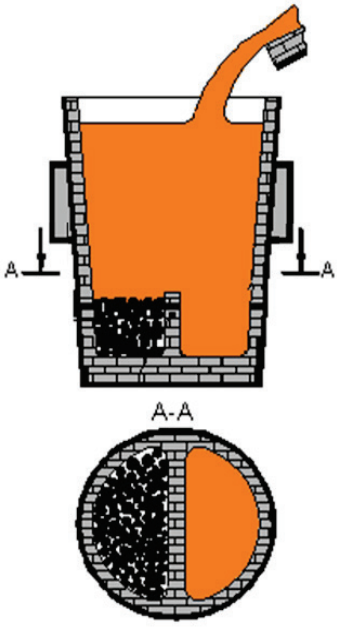


Figure 7 The Trigger method

- The Tundish–Cover process (Fig. 8) is a further improvement of sandwich method and is aimed at reducing the oxygen level inside the ladle by applying a special cover [1, 4, 9, 12]. A special dividing wall is located at the bottom of the treatment ladle to separate the area with nodulizing material and is the part to be filled first in order to avoid premature master alloy dissolution. A covering material is also required, though generally in lesser quantities than used in the Sandwich process.

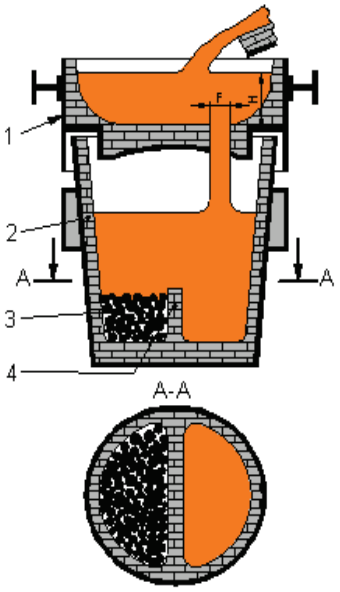


Figure 8 The Tundish–Cover process

The most difficult operation during the cast iron nodulizing with magnesium is introducing the nodulizing metal or its alloys to the melt [1-6, 12]. This is caused by a large density difference between cast iron (about 7 g/cm^3) and magnesium (about 1.7 g/cm^3) that leads to floating of magnesium.

The foundries production capacity in ductile iron can determine the type of nodulizing treatment or type of nodulizer [1-6, 12]. Nowadays, the treatment processes commonly used are those in the ladle, and those that use Fe–Si–Mg alloys as a nodulizer are applied in most of the foundries.

Continuing developments in liquid metal treatment technologies have made major contributions to the quality, performance and reliability of metal castings. Advances in melt conditioning, in magnesium treatments to produce ductile irons, and in nodulizing techniques have ensured that cast irons remain key and competitive engineering materials.

3 METHODOLOGY & MATERIALS

In order to modify these irons, developed in electric induction ovens (with chemical compositions according to [14]), classical nodulizing methods – the Open Ladle method, the plunging bell immersion (Plunging method), the Sandwich method, the Trigger method and one of the covered ladle methods, i.e. Tundish-Cover – were used (described above in Section 2).

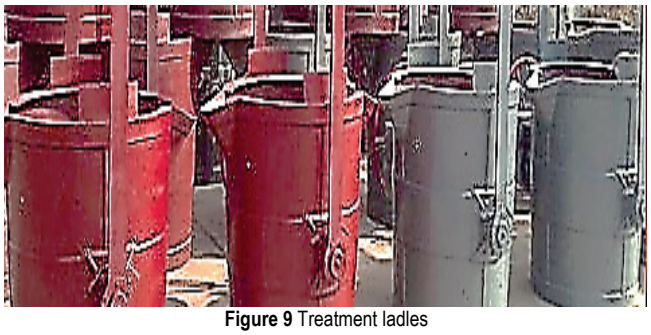


Figure 9 Treatment ladles

Table 1 Silicon based pre–alloys used in experiments [15]

Silicon based pre-alloys	Chemical composition (%)					
	Mg	Si	Ca	Al	Ce	Ba
FeSiMg 5	5	42	0.5	1.0	1.5	0.5
FeSiMg 6	6	42	0.5	1.0	1.2	0.5
FeSiMg 10	10	42	0.5	1.0	1.2	0.5
Nodulin 5.8	5.8	48	1.5	1.0	2.0	1.2

Figure 10 Silicon based pre–alloys used in experiments
(a) Fe–Si–Mg 5; (b) Fe–Si–Mg 6; (c) Fe–Si–Mg 10; (d) Nodulin 5.8

As nodulizers Fe–Si–Mg pre–alloys were used (Fig. 10), with different percentages of magnesium (i.e. 5, 6 and 10%), but also a special magnesium–silicon based pre–alloy, considered "light pre-alloy", category Nodulin, with composition given by Tab. 1 (according to [15]).

Among the nodulizing agents that may be advantageously used in the process are magnesium, magnesium–ferrosilicon, cerium (Ce) containing magnesium–ferrosilicon, and rare earth oxides [1, 2].

Under the practical conditions of nodulization process, in all our experiments, the same amount of iron, melted in an induction furnace (12.5 t), using one of the above mentioned technique, with one of selected pre–alloy, has been treated.

The experiments starts from a given capacity of liquid iron (1000 kg), which has a temperature range of 1350–1450 °C. The amount of nodulizing alloy used is between 1.2–1.8% of the quantity of treated iron, so that the remaining magnesium must be between 0.03 and 0.06 %. The pre–alloy are inserted in the ladle (granulation 20–40 mm), preheated in advance, to increase the magnesium assimilation. The treatment effect lasts between 5–30 min, during which time the casting of iron must be carried out at 1400–1450 °C.

4 RESULTS & DISCUSSIONS

In a series of experiments on cast irons intended for the casting of rolling rolls, the classical Plunging, Open Ladle, Sandwich and Trigger techniques were incorporated, including the Tundish-Cover. A very important factor for the assessment of nodulization process is the degree of magnesium assimilation by the treated cast iron (called also the yield of magnesium). It is a proportion between the amount of magnesium remaining in the alloy and the total amount of magnesium introduced to the cast iron during its treatment. The direct data concerning the discussed parameter are presented in Tab. 2. Different degrees of assimilation of magnesium into the iron were obtained, depending on the method and the type of nodulizing pre–alloy used in the experiments. This data is rendered in a synthesized way in a summary table (Tab. 2).

Table 2 Summary table on experiments

Nodulizing technique	Nodulizing agent (–)	Treatment temperature (°C)	Quantity of nodulizer (%)	Degree of magnesium assimilation (%)
Plunging method	FeSiMg 5	1450	1.8	28
	FeSiMg 6	1450	1.8	29
	FeSiMg 10	1450	1.8	32
	Nodulin 5.8	1450	1.8	32
Open Ladle method	FeSiMg 5	1450	1.8	33
	FeSiMg 6	1450	1.8	33
	FeSiMg 10	1450	1.8	33
	Nodulin 5.8	1450	1.8	34
Sandwich method	FeSiMg 5	1450	1.8	35
	FeSiMg 6	1450	1.8	35
	FeSiMg 10	1450	1.8	36
	Nodulin 5.8	1450	1.8	38
Trigger method	FeSiMg 5	1480	1.8	42
	FeSiMg 6	1480	1.8	43
	FeSiMg 10	1480	1.8	45
	Nodulin 5.8	1480	1.8	50
Tundish-Cover method	FeSiMg 5	1480	1.8	45
	FeSiMg 6	1480	1.8	47
	FeSiMg 10	1480	1.8	51
	Nodulin 5.8	1480	1.8	58

Unlike gray iron, which contains graphite flakes, ductile iron has an as–cast structure containing graphite particles in the form of small, rounded, spheroidal nodules in a ductile metallic matrix. Treatment to produce ductile iron involves the addition of magnesium to change the form of the graphite, followed by or combined with nodulizing of a silicon–containing material to ensure a graphitic structure with freedom from carbides. The research describes the in–ladle methods with silicon based magnesium pre–alloys treatment.

This study takes into account, the followings:

- The nodulizing agent (nodulizer), which indicates the optimal procedure when several categories of modifiers (Fe–Si–Mg and Nodulin) are available;
- The magnesium content of each nodulizing agent, corresponding to the chosen procedure,
- The degree of assimilation of magnesium, which shows the performance of the chosen process, depending on both the modifier used and the temperature of the treatment, the size of the ladle, the composition of the cast iron to be treated, the amount of cast iron elaborated and necessary for nodulizing etc.;
- The cost of the investment, for the adoption of an optimal process. A simple nodulizing ladle shall be considered as a basis, plus the costs of adapting the technologies.
- The flexibility of the used technique, which describes the elasticity of the process, the freedom to modify the treatment process, by improvement or alternative to the existing one;
- The smoke emissions, which shows how polluting the process may be, due to magnesium evaporation or the reaction smoke. Thus, a separate ventilation system is required for high emissions, which also raises the cost of investment.
- The sulphur restrictions, showing the maximum recommended sulphur content, from the preparation, before treatment, sulphur being a factor dictating the applicability of one process or another;
- The risk of the silicon growth when the Fe–Si–Mg range is used as a nodulizer.

Based on the results obtained in the performed experiments, we can conclude the followings:

- The classical modification procedures (Plunging, Open Ladle, Sandwich / Over pouring and Trigger) provide relatively low degrees of assimilation of magnesium embedded in the pre–alloys. For the purposes of increasing assimilation, practice shows that the Tundish-Cover process can be used at higher performance as alternatives to the classic techniques.
- The nodulizer's granulation (20–40 mm) was subject to the conditions of ensuring an optimal.
- A separate ventilation system is required for high emissions, which also raises the cost of investment. It should be noted that only one of the nodulizing technology (Tundish-Cover) complies with the severe environmental protection. The cover attached to the treatment ladle, considerably reduced the emission of smoke and flame, ensuring the protection of the foundry environment.

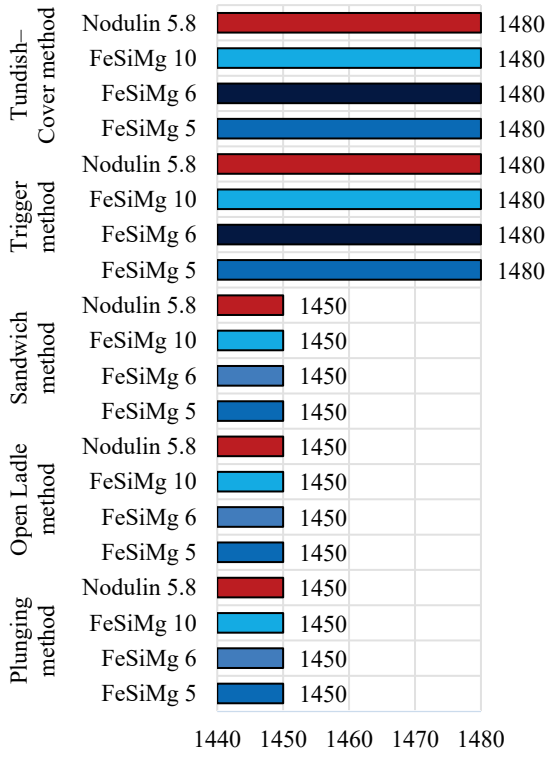


Figure 11 Treatment temperature (°C)

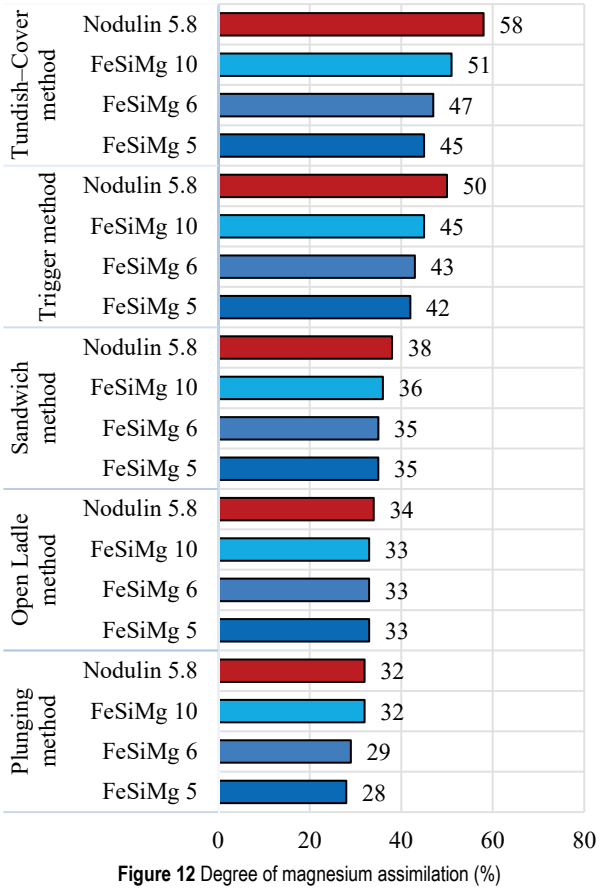


Figure 12 Degree of magnesium assimilation (%)

- There is a risk of silicon increasing in cast iron due to the nodulizing agent. In this respect, it was sought that the iron, in the melting phase, should contain minimum values prescribed by the standards.
- Most ladle treatment methods involve the use of magnesium–ferrosilicon alloys in specially prepared ladles as in the Sandwich and Tundish (covered ladle) processes. Compared to Open Ladle treatments, the use of a covered Tundish ladle gives better magnesium recovery with much less fume.

5 CONCLUSIONS

In the "in-ladle treatment method" the nodularizer alloy is placed in the bottom of the ladle whereafter liquid cast iron is filled into the ladle on the top of the nodularizer alloy. Depending on how the nodularizer alloy is placed in the ladle, the method is known as Open Ladle, Overpour / Sandwich, Trigger or Tundish-Cover treatment methods. These basic treatment methods are used in our experiments. Four different experiments were performed, for each method. In three of the experiments magnesium–ferrosilicon alloy with different magnesium content were used (5, 6 and 10%), and for comparison purpose, one experiment was done with Nodulin 5.8, a special magnesium–silicon based pre–alloy.

From the multitude of alternatives presented, in the case of nodulizing process, foundries can make these constructions themselves, at quite low costs. Everyone can choose the system according to the facilities, possibilities and needs of this sector. It all comes down to choosing a process, which by practical application leads to the best efficiency of assimilation, as a primary and economic purpose, but also to reduce, as far as possible, the costs of production and last but not least, to reduce the emission of gas and smoke, in order to achieve a clean climate, in these sectors with a high degree of pollution.

Proper nodulizing process of irons cannot be over emphasized, because this technological step defines the final microstructure and resultant properties and minimizes problems. The nodulizing process, if done correctly, produces the correct mechanical properties, improves machinability, and will decrease shrinkage. Therefore, the magnesium treatment is an important step in ductile iron processing.

6 REFERENCES

[1] Riposan, I. & Skaland, T. (2017). *Modification and inoculation of cast iron*. Stefanescu, D. M., Ed., Cast Iron Science and Technology Handbook. American Society of Materials: Cleveland, USA, 160-176. https://doi.org/10.31399/asm.hb.v01a.a0006315

[2] Ripoşan, I., Chişamera, M., Stan, S., Grasmo, G., Hartung, C., & White, D. (2009). Iron quality control during melting in coreless induction furnace. *AFS Transactions*, 117, 423-434.

[3] Skaland, T. (2001). Inoculation material improves graphite formation in ductile iron. *Modern casting, 91*(12), 43-45.

[4] Skaland, T. (1999). Ductile iron production – A comparison of alternative treatment methods. *Metal Asia, 7*(1), 11-15.

[5] Skaland, T. (1997). Ductile iron production – A comparison of alternative treatment methods. *Indian Foundry Journal*, 43, 27-37.

[6] Skaland, T. (1992). Production of ductile cast iron from high purity charge materials. *Scandinavian Journal of Metallurgy, 21*(2), 63-67.

[7] Zhang, W.-H., Ding, J., & Nie, F.-R. (2009). Nodulizing alloy and treatment of iron melt. *Foundry, 58*(11), 1176-1180.

[8] Zhou, H.-L., Yu, H.-Y., Sun, Y.-X., & Hu, J. (2013). Effect of nodulizer on chemical composition of ductile iron. *Foundry Technology, 34*(5), 584-586.

[9] Wang, C.-D., Sun, Y.-X., Li, M., & Guo, Z.-T. (2004). A review of common nodulizing treatment processes. *Modern Cast Iron, 24*(3), 62-64.

[10] Guo, Z. T., Sun, Y. X., & Li, M. (2006). Effect of Mg content in nodulizer on the absorptivity of Mg. *Foundry, 55*(6), 623-625.

[11] Lerner, Y. S. & Panteleev, G. V. (2003). Magnesium treatments in ductile iron production - Part 2. *Foundry Management and Technology, 131*(2), 24-29.

[12] Olawale, J. O., Ibitoye, S. A., & Oluwasegun, K. M. (2016). Processing techniques and productions of ductile iron: A review. *International Journal of Scientific & Engineering Research, 7*(9), 397-423.

[13] Kiss, I. & Hepuţ, T. (2002). The hardness of the cast iron rolls, assured by the alloy elements and the modification treatment of the graphite nodularity. *Scientific Bulletin of the University Politehnica Timişoara, Transactions on Mechanics, 47*(2), 169-174.

[14] STAS 9432-85: Rolling mills. Half-hard cast iron rolls specification. (in Romanian)

[15] STAS 11240-88: Nodulizing pre-alloys for cast iron. (in Romanian)

Authors' contacts:

Imre Kiss, PhD, Associate Professor
Politehnica University Timisoara,
Faculty of Engineering Hunedoara,
Department of Engineering and Management,
5, Revolutiei, 331128 – Hunedoara, Romania
E–mail: imre.kiss@fih.upt.ro

ISSN 1846-6168 (Print), ISSN 1848-5588 (Online)
https://doi.org/10.31803/tg-20210304095657

Preliminary communication

Six Sigma Approach to Enhance Concurrency of the Procurement Process for Raw Materials

Atanas Kochov*, Aleksandar Argilovski

Abstract: This paper presents the improvement of the procurement process for raw materials in a real manufacturing company supported by the Lean Sig Sigma as structured approach to deliver the improvement. The manufacturing company that is a subject of this paper have received a significant amount of complains regarding the internal purchase orders approval process and the overall procurement process of the company from both internal employees and external vendors and contractors. Considering that the company is procuring the raw goods from selected vendors, therefore the entire manufacturing plan depends on these materials, the company decided to improve this process trough Lean Six Sigma. The Lean Six Sigma approach was selected in order to obtain the improvement in a short time, based on indicators that were previously analyzed and prioritized. The paper focuses on simplifying of the process trough decreasing the number of mandatory steps.

Keywords: concurrent engineering; Lean; manufacturing; procurement; raw materials; Six Sigma

1 INTRODUCTION

The purchasing of the raw materials is one of the key features of the production planning and control process. Although sometimes this process is viewed as administrative and repetitive, it should be strategic and based on the current needs for purchasing of the companies.

It is one of the most important factors that affects the shortening of the production plan and therefore enhancement of the competitiveness of the entire company on the market. Once this process is optimized and thought through, it could also generate a lot of savings for the companies as well as improve the relationships with the external contractors, vendors, and suppliers.

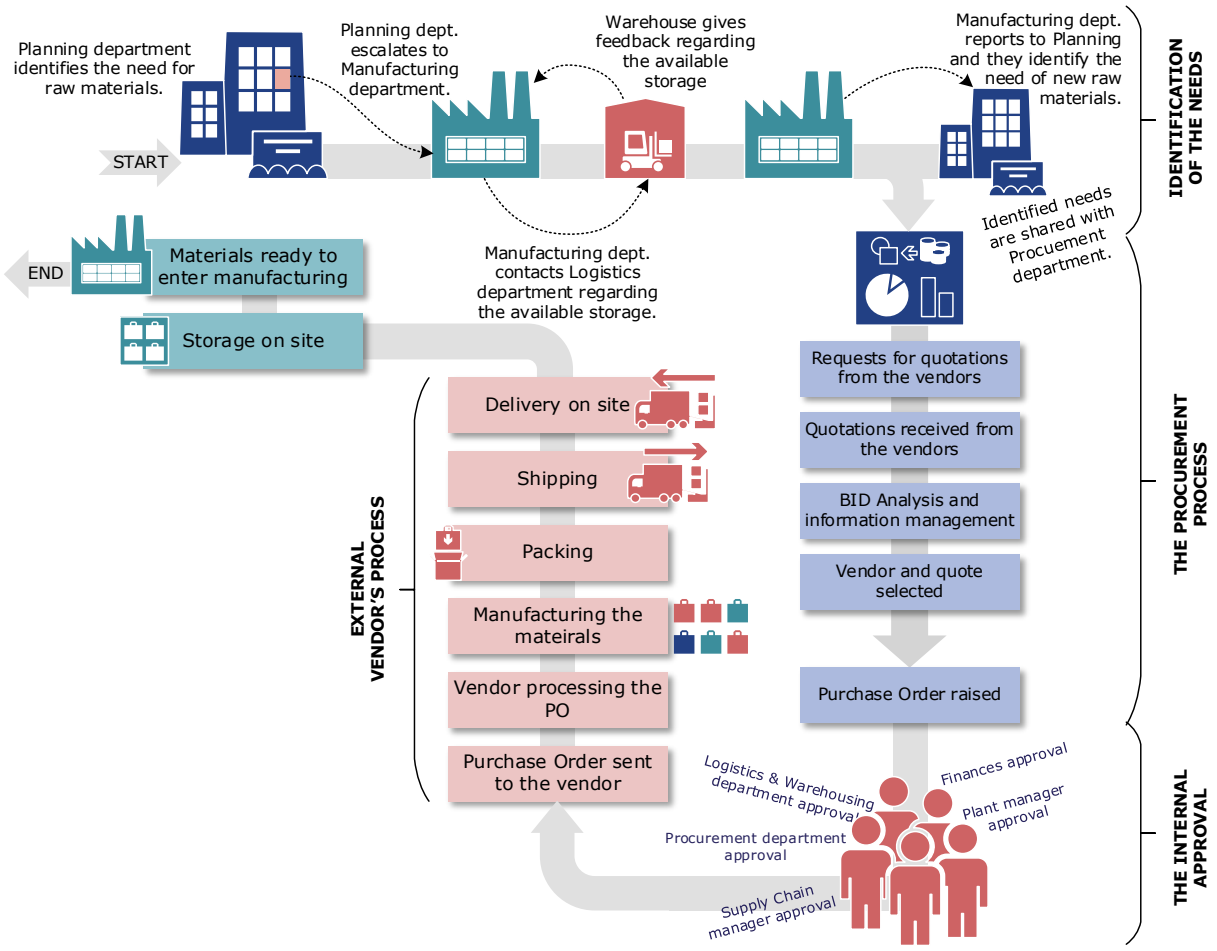


Figure 1 Map of the current process

Six Sigma puts the customers (or suppliers) first and uses the facts and data to drive better solutions and improve processes [1]. Six Sigma efforts target three main areas: improving customer (or other types of associates) satisfaction, reducing process cycle time and reducing defects.

The case given in this paper is focused on improving a process to both reduce the process cycle time but also improve the relationships with one of the most important associates of the production companies – the suppliers of raw materials. Besides having the supplies responsible for the design, quality or performance of the materials, the production companies must work closely and transparently with the main suppliers. Considering that the manufacturing companies are highly dependent on the suppliers, actions such as these small improvements in the communication or easing the procedures for collaboration, can prevent a factory collapse, in more senses, starting from not producing enough, to building inventory or even cause environmental issues due to inadequate products or supplied materials.

PO (or purchase order) could be defined as "request for purchase", in fact is an official confirmation from the buyer that they accept the quotation issued from the seller and they are willing to purchase the goods or services offered by the seller. A PO is the simplest type of fixed price contract [2]. The shortening of the administrative or technical process of issuing a PO, will help both the production company and the seller's company. Besides the enhancement of the production plan and the reduction of the responsibilities for the employees, the improvement of this process will also improve the communication between both sides which leads to opportunities for both sides (the buyer and the seller) such as further business collaborations, contracts, discounts etc. The benefit of this improvement could be monetarized through the reduction of manpower and shortening of the production plan.

The problem that is covered in this paper is taken from real manufacturing company (Company A). The extended process of identification of the needs for purchasing and the purchasing itself in this company is illustrated in Fig. 1. The suppliers of this company are constantly complaining about the significantly long time for receiving of the official order (PO) from the manufacturing company counted from the moment when they issue their financial quotation. The current lead time for defining the needs and releasing PO for raw materials in the Company A is approximately 51 working hours.

The project will be led according to the DMAIC framework (define, measure, analyse, improve and control) since this improvement is being implemented on already existing process [3].

The project team is consisted of:

- Project sponsor (1 member) – business representative (in this case the Plant manager) and project initiator,
- Six Sigma Black Belt (1 member) – to translate business goals into Six Sigma deliverables, define Six sigma strategy and mentor other involved sides.
- Six Sigma Green Belts (2 members) – for project tools execution to deliver results.

Due to the type of the process (cross-departmental) several other employees from different departments were contacted to gather the needed data (especially in the Measure phase).

2 DEFINE

To define the problem, the team will issue problem and goal statement based on the requirements of the project sponsor (the Plant Manager of Company A) as well as the voice of the stakeholders that are directly involved in this process. Other project management aspects such as resources, time and cost are also finalized in this phase, but this will not be showcased within this paper in details.

The time required to implement this improvement is estimated to be three months with minimum costs needed for the improvement of the purchasing system.

2.1 User Requirements

This process has several users such as the different suppliers of raw materials and all the internal departments that are included in this process such as Planning, Purchasing, Manufacturing, Transport & Logistics, Finances, Supply Chain and finally, the sponsor of the project – the Plant Manager of Company A.

To gather user requirements, Six Sigma offers tool that is as simple as "Voice of the customer (VOC)". "Customers" of this process are all above mentioned sides that are part of the process in any way. Fig. 3 is showcasing the full VOC analysis for the project.

2.2 Problem and Goal Statement

The problem and the goal statements are one of the main starting point of the Six Sigma project. The statements should be based on a brainstorming session within the team – they should be short and perfectly clear to the team. Fig. 2 is showing the "Problem Statement" and the "Goal Statement" for this project.

PROBLEM STATEMENT	GOAL STATEMENT
"The process of procurement of raw materials in the company needed as base for the manicuring process is too long and complicated which results with delays of the manufacturing and unsatisfied clients and suppliers.	"The goal of the project is to shorten the time needed for the needs identification and procurement of the raw materials, reduce the steps and approvers and increase the concurrency of the process.

Figure 2 Problem and goal statements

Further explanations of these statements could be done in a separate document, if needed.

CUSTOMER	WHY ARE THEY SAYING IT?	WHAT DO THEY NEED?
"We wait for several days to get the PO after issuing the quote"	Suppliers need the decisions as soon as possible because they plan all quoted materials same as the ordered ones.	They need standard process with defined time of waiting to get PO after the Company's decision.
"Do not ignore our follow-up e-mails"	The suppliers need information in order to plan their capacities. They could take this as bad collaboration from the Company A.	They need frequent feedback even if this feedback is negative (not accepting the quote).
"Asking/giving quotes for the same time over and over is counterproductive – we are serious in doing business with you"	The suppliers spend a lot of time to prepare the quotes for the same quantities and materials over and over.	The supplier means that they want to set mutually standardized process for procurement of these standard materials
"Orders usually don't reflect the number of the exact number of quoted parts"	Company A sometimes takes liberty to set more parts in the orders than the quoted number. This is not good for supplier's plan.	Previously defined specification regarding the quantities that will satisfy the production and the storage requirements of Company A.
"You usually ask us to ship/prepare the parts before you officially place the PO"	The suppliers can't send their parts before the business is confirmed with a PO.	Understanding that the PO is crucial confirmation for them to even start preparing the materials for dispatch.
"The relationship with our suppliers is not very good because we are very late with the POs"	Procurement employees think that the process of internal PO processing is very slow.	Reduction of the administrative work.
"We received strikes from our clients that didn't received our products on time"	Not having enough raw materials to produce the parts on time resulted with losing business with the clients of Company A.	Process that will ensure that all raw materials are in Company A just in time.
"We don't have enough space to store all materials"	Logistics (Warehouse) department is struggling with the quantities of raw materials sometimes.	The inventory of raw materials should be as optimized as possible because inventory generates waste.
"We noticed that the discounts given by the suppliers are decreased by 40% in the past year"	Procurement team is not able to reach their discounts goals from the suppliers because they have been unreliable in the past.	Fast and transparent process is needed.
"The project plan is changing frequently to reflect the available raw materials"	Planning department should modify the plan according to available raw materials – no matter if these parts are not critical.	Just-in-Time delivery of all raw materials in order not to produce uncritical parts just to keep the equipment running.
"Approving the POs is not my primary job, so I am aware that I am late with the approvals"	The Plant Manager is aware that they are late with the approval of the POs.	Introduce different type of control and exclude the Plant Manager and other unnecessary approvers from the process.
"There are too many levels of approval, we have to follow-up them all the time"	Procurement is struggling to make all managers/supervisors to approve on time.	Exclude all unnecessary approvers from the process and find a way to have them responsible earlier in the process.

Figure 3 Voice of the customer

As stated in Fig. 2, the main goal is to transform this process into more concurrent (parallel) process and therefore shorten the time needed for processing the orders. Besides shortening and clarifying the procurement process, this will shorten the production plan as well as reduce the risks of deficiency of raw materials for the production process. To clarify this, the project team expanded the goal statement and brainstormed several additional benefits/points how to transform the current traditional procurement into contemporary procurement that will be driven by the Lean philosophy and concurrent engineering fundamentals.

As seen on Fig 4., thanks to the LEAN and concurrent engineering principles, some of the usual steps of the procurement process will be transformed which means smaller order sizes, agility, frequent control, performing more steps parallelly, standardization of the steps and implementation of Just-In-Time (JIT) methodology. These directions will be the focus of the team during the Improve phase, but also will help to define the Key Performance Indicators that will measure the success of this improvement after the implementation.

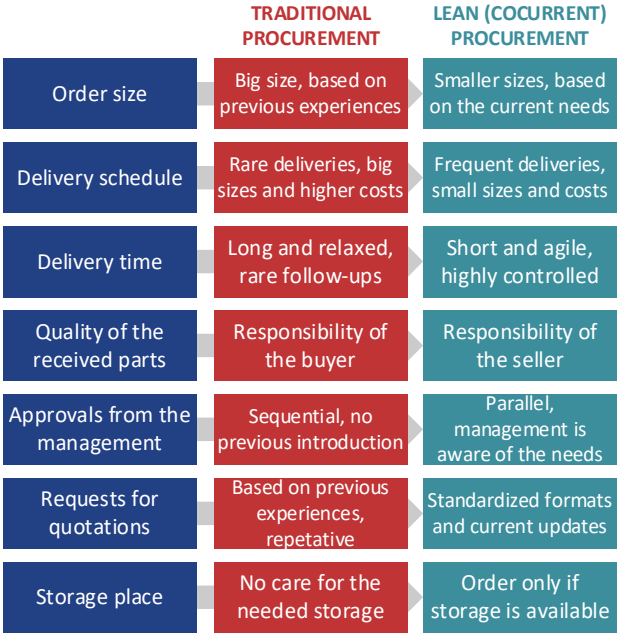


Figure 4 Transformation of traditional procurement to LEAN (concurrent) procurement process

2.3 SIPOC

Considering that the Define phase is laying-out the general characteristics of the problem/process, the SIPOC gives high-level management that simplifies and separates the process variables in five groups: **S**uppliers, **I**nputs, **P**rocess, **O**utputs and **C**ustomers. The SIPOC analysis for the discussed problem is shown in Fig. 5.

S	I	P	O	C
Raw materials supplier	Production plan	Production needs identification	Forming accurate specification	Raw materials supplier
	Raw materials needs	Request for quotations		
Budget for raw materials	Quotations from the suppliers	Issuing PO	Issuing PO to the supplier	Procurement department
	Approved budget	Management approvals		Manufacturing department
Management approvals	Production needs and requests	Supplier gets the PO	Raw materials (goods) delivery	Plant Manager
		Preparation of the raw materials		
		Shippment		
		Good received on-site		

Figure 5 SIPOC analysis

3 MEASURE

The purpose of this step is to thoroughly understand the current state of the process and collect reliable data on the process time, quality and costs and use that data to identify possible bottleneck, to set clear and measurable goals and have real figures for comparation and confirmation of the improvement at the end of the project [1].

3.1 Mapping of the Current Process

The current process was observed several times so that the team be able to map it in a simple flowchart. Fig. 1 is giving more realistic view on this process but when it comes to using the Six Sigma tools in the right way, a flowchart should be created to have clear overview of the steps. This will also help to set the KPIs and identify the value-added and non-value-added steps in the process.

The flowchart for the process is shown in Fig. 6. On a first look, it is obvious that this process is not predictable and straight forward. It includes few decisions that could end-up with at least two outputs, sub-steps that are time consuming, manual steps etc. This process could be easily separated in few different processes such as (a) the identifying of the needs, (b) the administrative procurement process (c) the supplier's process. For this process, this is unwanted due to the connection between all these sub-processes. This process is specific, and all of these steps need to be integrated and the participants to be as involved in each one of them as much as possible and as early as possible.

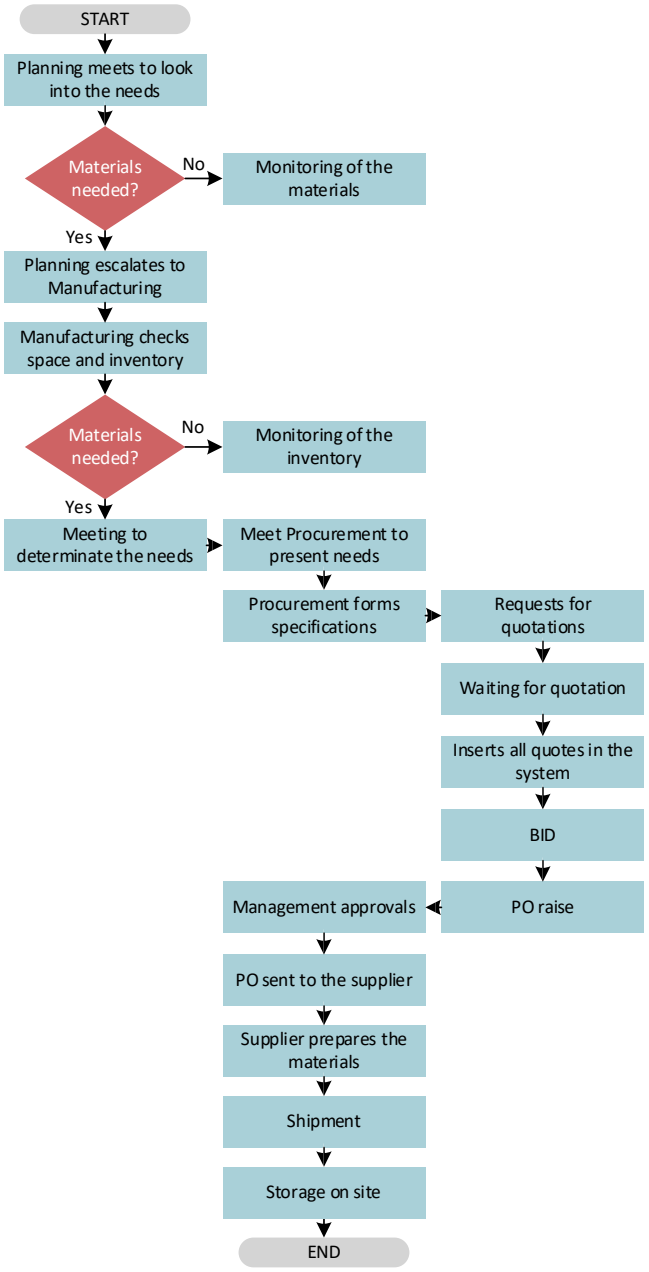


Figure 6 Map of the current process

It is easy to observe that the process is sequential – there are many "walls" (Fig. 7) [4] between the departments that are driving this process and these walls are the main sources of miscommunications, delays and variations of this process.

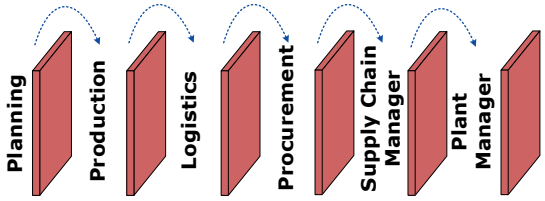


Figure 7 "Walls" between the stakeholders of the process

3.2 Key Performance Indicators

Tab. 1 is showing the generated and measured KPIs of the current process. The KPIs are generated based on the goal of the project because these KPI values will be compared with the same values measured at the end of the project.

Table 1 Key performance indicators summary

Indicator	Unit	Value
hours needed for vendors to receive PO	working hours	16,5
mistakes in the Purchase Orders	mistake/month	9
discounts from the suppliers monthly	€	4k
delays of parts delivery due delay of the PO	working hours	16
response time to vendor's questions	h	8
number of steps in the procurement process	steps	22
number of approvers	person	7 to 10
length of the full process	h	116

4 ANALYSE

The Analyse phase for this project will focus on two main things: the investigation of the root cause and identification of the obsolete steps in the current process – the steps that do not add any value for the clients/suppliers or the Company A itself. The data is gathered mostly by observation of the current process and interviewing.

4.1 5 Why

The 5 Why analysis [5] is an easy and creative way to identify the root cause of the problem and give one more direction to the team for designing better solution.

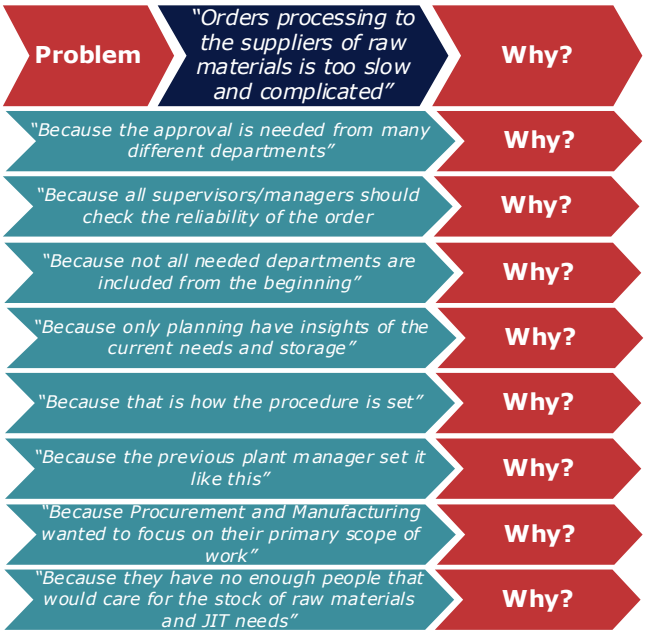


Figure 8 5 WHY analysis

The analysis shown on Fig. 8 states gives a perspective what could be the potential root causes for this problem, finally concluding that the careless approach to stock and Just-in-Time needs of raw materials is causing the problems.

4.2 Value-Added Analysis

To identify which steps are obsolete in this process, Value-added analysis [1] will be performed. This analysis consists of three different types of activities that are assigned to each step of the process [6]. These activities are defined as such:

- value-added activities – activity/step which adds any value that a customer is willing to pay for to the manufacturing company,
- non-value-added steps – opposite to the value-added steps, these activities do not add any value to the finished product, these activities consume time, space and resources but they do not contribute to satisfy the customer's needs at the end, these steps also generate waste (Fig. 9) [6],
- necessary steps – these activities/steps are also consuming time, space and resources and do not contribute to produce what the customer wants, but these steps are needed or mandatory in the process.

Figure 9 The six wastes of LEAN

The goal of the value-added analysis is to classify all steps of the process as steps that add value, steps that do not add value and necessary steps [1]. There should always be steps that add value and these steps should stay in the process. The ones that do not add value should be immediately eliminated, and the ones that are necessary, even though they don't add any value, they cannot be eliminated, therefore these steps should be optimized or reduced to minimum.

For this analysis, a flowchart is needed (could be used the one in Fig. 6) and a table laying out all the steps. We will also get back to the Measure phase outcomes and use the results in the table to find out which steps are doing the most "damage" to the process.

Since the team is mostly focused on shortening the time of this process, the lead time of all steps should be measured and set in the table (in the Lead time column, all values are in hours). After that, all steps are labelled according to the fact if they add value (VA column) to the process/products or the company, they do not add value (NVA column) or they are simply necessary (N column). After this segregation, the "non-value-added" steps are being eliminated, and then the team decides for the further improvement or rearrangement of the value-added and the necessary steps (Action column will state the future of the given step of the process). Tab. 2

is summarizing the Value-added analysis for the problem reviewed in this study.

Table 2 Value-added analysis

Step	Lead time	Type of Value-added			Action
		VA	NVA	N	
Meeting for the needs of raw materials	2			2	Improve
Escalation to Manufacturing	0,5		0,5		Eliminate
Checks in Warehouse	1		1		Eliminate
Feedback from Warehouse	0,5		0,5		Eliminate
Manufacturing & Planning meet to determinate needs	1,5		1,5		Eliminate
Meeting with Procurement to present needs	0,5		0,5		Eliminate
Procurement forms specification	2	2			Keep
Request for quotation	2	2			Keep
Waiting for quotations	24			24	Keep
Insert all quotes in the system	1			1	Improve
BID analysis	1			1	Improve
Vendor selection and quote selection	1			1	Improve
PO Raise	0,1			0,5	Improve
Manufacturing approval	1		1		Eliminate
Planning approval	1		1		Eliminate
Logistics Approval	1		1		Eliminate
Finances checks available budget	3		3		Eliminate
Finances approval	1			1	Keep
Procurement approval	1		1		Eliminate
Supply chain manager approval	2		2		Keep
Plant manager approval	3		3		Eliminate
PO sent to the vendor	0,5			0,5	Keep
Vendor process the PO	1			1	Keep
Manufacturing of the materials	40	40			Keep
Packing	2	2			Keep
Shipping	16			16	Keep
Delivery on site	2			2	Keep
Storage on site	3			3	Improve
Materials enter manufacturing	1			1	Improve
Total (h)	116	46	16	54	

5 IMPROVE

During this step, the team will implement all actions that were identified in the Analyse phase. For this given case, considering that the team is improving a strategic process of the company, they should ensure that this process is stable, predictable and meets customer requirements. Thanks to the Six Sigma's structured and step-by-step methodology, all of the mentioned process characteristics were already taken into consideration in both Measure and Analyse phases. At the end of the phase the team should also compare the results with the baselines given at the beginning of the project (especially with the set end measured KPIs).

To illustrate the process transformation, "To-be" process map (Fig. 10) was created where the obsolete steps are moved to the side of the flowchart and new connections or steps are created.

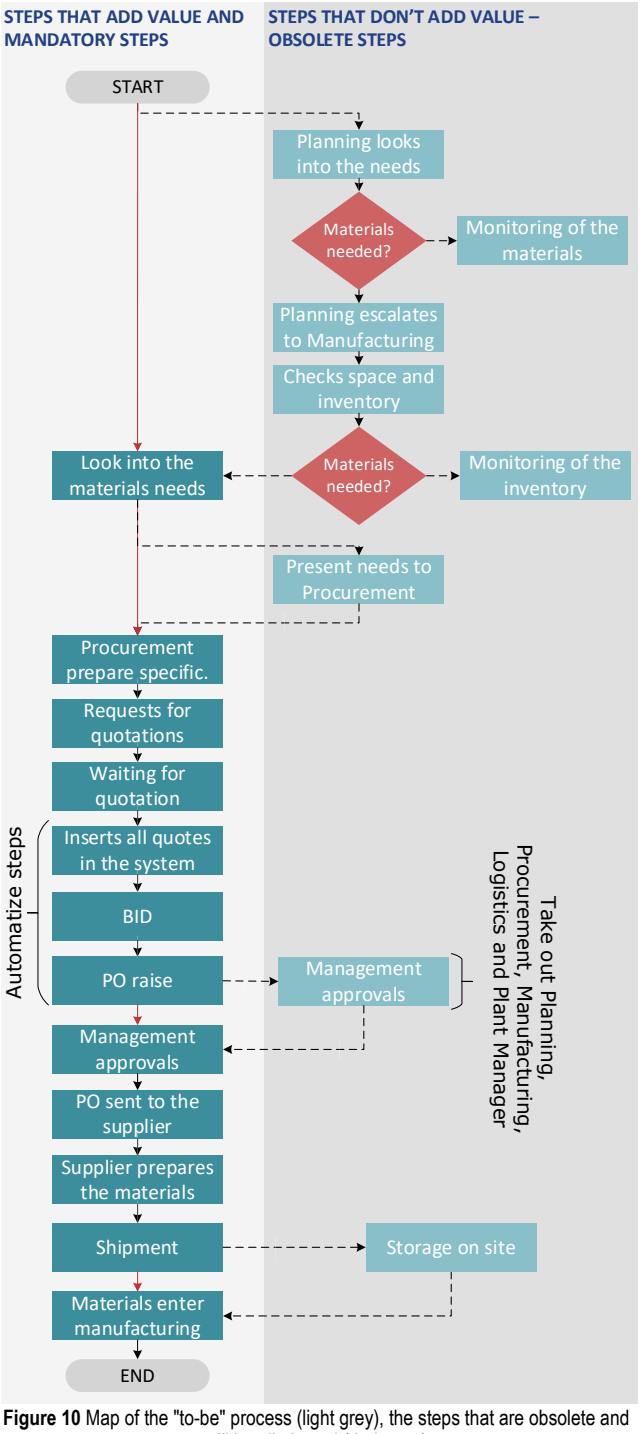


Figure 10 Map of the "to-be" process (light grey), the steps that are obsolete and will be eliminated (dark grey)

The final process, for comparation to the one on Fig. 6, could be seen on Fig. 11 with all removed and modified steps.

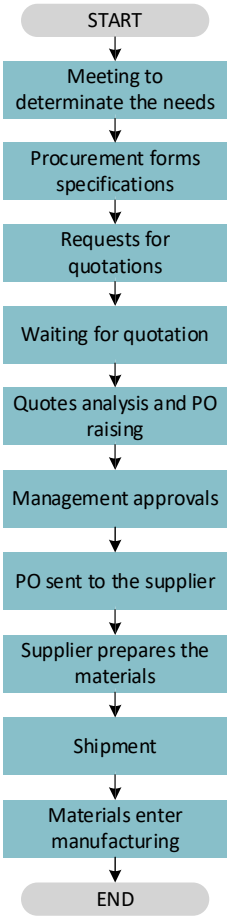


Figure 11 Map of the improved (final) process

5.1 Compare Results to the Baseline

The KPIs set and measured previously in the Measure phase of the project, are now re-measured. The goal is to quantify the success of the improvement after the implementation of the process.

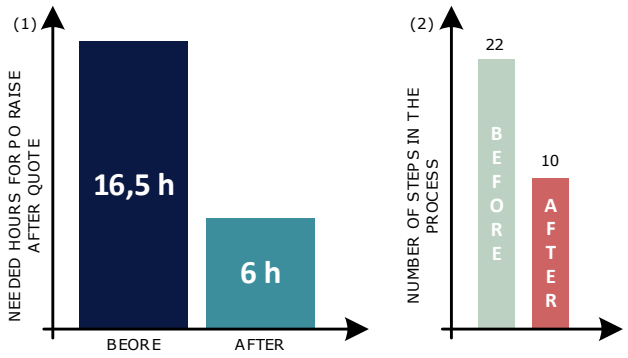


Figure 12 (1) Needed hours for raise a PO after the quote, (2) number of steps in the process before and after the improvement

The results of the re-measurement are given in Tab. 3, as well as on the chart in the following figures (Fig. 12 and Fig. 13).

The improvement of many KPIs is notable from Tab 3. For example, the hours needed for the suppliers to receive the PO was decreased from 16,5 working hours to only 6, which is mostly thanks to the reduced number of approvals by the different departments that was also reduced from 7 approvers to only 2 mandatory approvers.

Table 3 Comparation of the Key Performance Indicators measured in Measure phase and the current values of the same KPIs

Indicator	Unit	Before	After
hours needed for vendors to receive PO	h	16,5	6
mistakes in the Purchase Orders	#	9	0
discounts from the suppliers monthly	€	4k	12k
delays of parts delivery due delay of the PO	h	16	0
response time to vendor's questions	h	8	1
number of steps in the procurement process	#	22	10
number of approvers	#	7 - 10	2
length of the full process	h	116	90

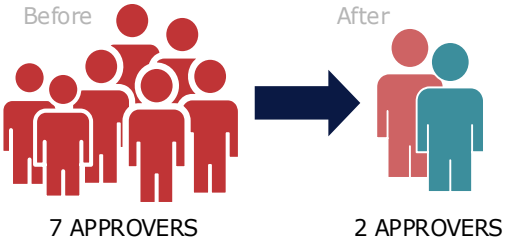


Figure 13 Number of PO approvers before and after the improvement

6 CONTROL AND MONITORING PLAN

The modified process must be accepted by both internal stakeholders (company's departments) and external sides (vendors, suppliers and customers) in order to keep transparency and avoid miscommunications or generating waste (generating inventory, overproduction, transportation related waste of time, unnecessary steps etc.) in the future.

Internally, in the company, this will be performed in the following order:

- the procedure for procurement of raw goods will be completely revised in compliance with the internal Quality Management System,
- all relevant employees will be trained for this procedure,
- to avoid additional miscommunications, the change will also go through the internal Management of Change process where the entire management is responsible for understanding, approving, and sharing this change with their teams.

The external vendors should also be introduced to the process change due to compliance with the quality assurance standards up to a level of details which is defined in the non-disclosure agreement between the Company A and the possible suppliers of raw materials. The transparent approach regarding the process changes with the suppliers is mandatory if the Company A is looking forward to improving the communication and business with the suppliers.

The process will be monitored in the following steps that are considered to be the bottlenecks of the process:

- the Finances Department will be responsible to standardize a procedure/process for just-in-time

approved funds for raw materials due to the importance of these materials for the overall production – Finances will frequently monitor the budget and make sure that funds are available in the right time,
- the Procurement manager will be responsible to perform a weekly audit of randomly selected vendors including the filled POs, the communication between the suppliers and the internal teams and the delivery of the materials,
- the Plant Manager will be responsible to audit the process - monthly,
- the attendance on the initial meeting for discussion regarding the needs will be mandatory and attendance tracker will show who, when and why was or wasn't attending the meeting,
- Planning department will be responsible to standardize a procedure for just-in-time purchasing and arrival of the raw materials – Planning will be responsible for implementation of this procedure as well as monitoring it,
- All managers approvals should be acquired within one hour after the PO release (this only applies to the raw materials POs), if not, needed approvers will be highlighted by the system and automatically followed-up.

All these monitoring/controlling actions will be integrated in the new procedure for procurement of raw goods as well as the above-mentioned processes for JIT funds approvals and arrival of raw materials.

7 CONCLUSIONS

The purpose of this study was to improve the process for purchasing of raw materials in a real manufacturing company. The goal of the improvement was to enhance the concurrency of the process using the Lean Six Sigma framework for process improvement. The purchasing of the raw materials is one of the key aspects in the production planning and control process. This process used to be very repetitive, administrative and sequential which could be observed in the several flowcharts presented in the paper which was not sufficient for the company considering that this process is strategic and should be based on the optimized and Just-in-time needs for purchasing of the raw materials.

During this study, the team was using the DMAIC (define, measure, analyze, improve and control) framework to implement the improvement. The focus of the study is the Analyze and the Improve phases where the Value-added analysis is performed in the full scale. This analysis helped the team to reduce the number of steps in the process from 22 in the initial process to only 10 in the final process which is sufficient for this project to be a success. The analysis also has shown that many of the steps are repetitive and should be integrated and possibly automated. The number of meetings as well as number of PO approvers was set to bare minimum which saved at least 12 working hours. The full length of the process was brought from 166 working hours down to 92 hours for execution of the entire process including the needs identification, administrative procurement process and the delivery of the materials.

Due to the highly complicated process at the beginning, Six Sigma was the right choice for this improvement considering its facts-based and step-by-step approach which helped to clarify the process steps and all the involved sides.

8 REFFERENCES

[1] George, M. L. Rowlands, D., Pric, M., & Maxey, J. (2005). The Lean Six Sigma Pocket Toolbook: A Quick Reference Guide to 100 Tools for Improving Quality and Speed, 1st Edition.
[2] (2017). A guide to Project Management Body of Knowledge: PMBOOK Guide – Sixth Edition, Project Management Institute.
[3] Kochov, A. & Argilovski, A. (2020). Case Study: Six Sigma Project for Reducing Manual Handling of Materials in Real Manufacturing Company. *Tehnički glasnik, 14*(4), 499-506. https://doi.org/10.31803/tg-20201002115534
[4] Prasad, B. (1996). *Concurrent Engineering Fundamentals. Vol I: Integrated Product and Process Organization*. https://doi.org/10.13140/RG.2.1.2613.0005
[5] See https://kanbanize.com/lean-management/improvement/5-whys-analysis-tool
[6] Womack, J. P. & Jones, D. T. (1996). Lean Thinking: Banish Waste and Create Wealth in Your Corporation. *Journal of the Operational Research Society, 48*(11). https://doi.org/10.1038/sj.jors.2600967

Authors' contacts:

Atanas Kochov, PhD
(Corresponding author)
Faculty of Mechanical Engineering – Skopje,
Karposh II bb, 1000 Skopje, Republic of North Macedonia
+389(0)71-299-299, atanas.kochov@mf.edu.mk

Aleksandar Argilovski, MSc
Faculty of Mechanical Engineering – Skopje,
Karposh II bb, 1000 Skopje, Republic of North Macedonia
+389(0)71-254-429, argilovski@hotmail.com

ISSN 1846-6168 (Print), ISSN 1848-5588 (Online)
https://doi.org/10.31803/tg-20210326111551

Preliminary communication

Applying Simulation Modelling in Quantifying Optimization Results

Ratko Stanković*, Diana Božić

Abstract: Improvements achieved by applying linear programming models in solving optimization problems in logistics cannot always be expressed by physically measurable values (dimensions), but in non-dimensional values. Therefore, it may be difficult to present the actual benefits of the improvements to the stake holders of the system being optimized. In this article, a possibility of applying simulation modelling in quantifying results of optimizing cross dock terminal gates allocation is outlined. Optimal solution is obtained on the linear programming model by using MS Excel spreadsheet optimizer, while the results are quantified on the simulation model, by using Rockwell Automation simulation software. Input data are collected from a freight forwarding company in Zagreb, specialized in groupage transport (Less Than Truckload - LTL).

Keywords: cross docking; gates allocation; optimization; quantifying; simulation

1 INTRODUCTION

Because of the growing competition on the global market and more complex customers' requirements, freight forwarding companies must constantly improve their operations and create competitive advantages in terms of timing, quality and cost. For a groupage transport (Less than Truck Load - LTL) specialized freight forwarding company, optimal cross dock gates assignment is one of the crucial factors in improving the performance of the cross docking operations [1]. Handling of freight in a cross dock terminal is labour intensive, and workers must quickly transfer freight during a short time period [2]. This is a typical optimization problem in logistics, which can be solved by methods of linear programming [3].

Input data are collected from a freight forwarding company in Zagreb, specialized in groupage transport. Optimal solution of the company cross dock receiving gates is obtained on the linear programming model, by using MS Excel spreadsheet optimizer Solver. Since the improvement comparing to the company empirical solution cannot be quantified in physically measurable values, it isn't suitable for presentation to the company stakeholders.

In order to quantify the improvement achieved by optimization in units of time, which is in this case the most important key performance indicator (KPI), the simulation model of inbound cross docking operations is designed, by using Rockwell Automation simulation software Arena.

Two simulation experiments, with the same input data are performed, first with the empirical solution the company normally use and the second with the optimized solution obtained from the linear programming model. The results of the experiments enable comparing throughput time (duration of cross docking operations) as the KPI which is required.

This way, the simulation modelling enables quantifying the improvement of cross docking operations in physically measurable values, in case when the linear programming model objective function is expressed as a non-dimensional value.

2 CROSS DOCKING AND GROUPAGE TRANSPORT

Generally, a cross dock terminal is a point in the supply chain where incoming shipments are transferred to outgoing delivery vehicles, with minimal internal processing and storage delay time. The main purpose is to enable economies in transportation by shipment consolidation but also a reduction of lead time and a decrease of inventory levels. In a cross dock terminal, shipments are unloaded from incoming trucks, moved across the terminal, sorted by outbound destinations and finally loaded onto outgoing trucks [2].

Groupage transport or Less-than-Truck-Load (LTL) is a type of road transport, based on consolidating (grouping together) shipments dispatched by several different shippers, for several different consignees, into the same truck load. The main benefit of consolidation is an optimal utilization of the vehicle payload, which enables reduction of transport costs. Besides the road network, the main infrastructure of groupage transport are cross dock terminals (XD terminals), operated by freight forwarders.

Groupage transport is an important segment of the freight forwarders services, therefore any improvement in cross docking performances have significant impact on their competitiveness [4].

In order to get relevant information and input data, analysis of the freight forwarding company cross docking operations, focussed to the receiving gates allocation, was performed in February 2021. Due to limitations of the software tools (academic versions) only a representative segment of the XD terminal is modelled, both by the linear programming model and by simulation model. However, the conclusions drawn from the results of the optimization process and from the optimization experiments may be considered relevant for the entire system.

3 OPTIMIZING RECEIVING GATES ALLOCATON BY APPLYING LINEAR PROGRAMMING MODEL

Optimization of the XD terminal gates assignment is actually a resource allocation problem, which can be mathematically depicted by a linear programing model, the

resource allocation model. Optimal assignment of the XD terminal gates to the incoming trucks is related to the quantity of goods (number of pallets) for each destination zone and Manhattan distance between each receiving gate and the respective consolidation zone.

3.1 Manhattan Distance

As shown in Fig. 1, Manhattan Distance or Taxicab Distance is the distance between two points measured along axes at right angles. The name alludes to the grid layout of the streets of Manhattan, which causes the shortest path a car could take between two points in the city.

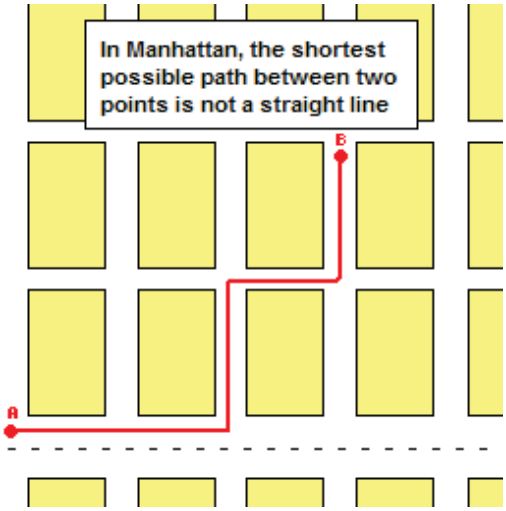


Figure 1 Manhattan Distance [5]

The reason for implementing Manhattan Distance instead of Euclidean Distance is because forklifts also follow similar paths within the XD terminal (instead of buildings there are pallet racks or rows). Also the actual distances in meters are not important, but ratios of distances between the gates and the consolidation zones, as shown in Fig. 2. The distances in the mathematical model are expressed in unit Manhattan Distances, where the distance between a gate and the closest consolidation zone (d_{11}, d_{22}, d_{33}, d_{44}) equals 1 unit.

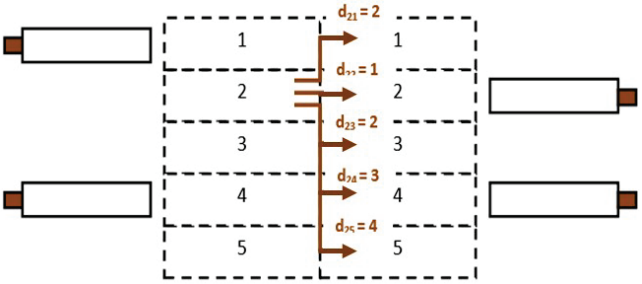


Figure 2 Unit Manhattan Distances in the XD terminal [6]

Manhattan Distance d_1 between two vectors $p = (p_1, p_2, \ldots, p_n)$ and $q = (q_1, q_2, \ldots, q_n)$ in n-dimensional space is given by the Eq. (1).

$$d_1(p, q) = \|p - q\|_1 = \sum_{i=1}^{n} |p_i - q_i| \tag{1}$$

3.2 Mathematical Model

A linear programming model is designed to mathematically describe the problem of optimizing the receiving gates allocation to incoming trucks, as follows.

Objective function:

- To minimize the quantity of goods moved and the distances passed by the forklifts (sum of products of quantities and respective distances), as given by the Eq. (2).

Constraints:

1) One receiving gate must be allocated to each inbound truck, as given by the inequity (3).
2) Each receiving gate can be allocated to only one or none inbound truck, as given by the inequity (4).

Input data:

- Number of inbound trucks;
- Quantity of goods (number of pallets) for each consolidation/destination zone, in each inbound truck;
- Total number of receiving gates;
- Total number of consolidation zones;
- Manhattan Distances from the receiving gates to the consolidation zones.

The mathematical model that encompasses all the elements of the problem is given by the following mathematical structure:

$$min\, F = \sum_{i=1}^{n}\sum_{j=1}^{m}\sum_{k=1}^{l} q_{kj} \cdot d_{ij} \cdot x_{ik} \tag{2}$$

$$\sum_{i=1}^{n} x_{ik} = 1 \quad \forall \quad k = 1, \ldots, l \tag{3}$$

$$\sum_{k=1}^{l} x_{ik} \le 1 \quad \forall \quad k = 1, \ldots, n \tag{4}$$

$$x_{ik} \in \{0, 1\} \quad \forall \quad i = 1, \ldots, n \tag{5}$$

$$n \ge l \tag{6}$$

Where:

q_{kj} - number of pallets in inbound truck k for consolidation zone j

d_{ij} - Manhattan Distance between receiving gate i and consolidation zone j

x_{ik} - decision variable (binary): 1 - receiving gate i allocated to incoming truck k; 0 - receiving gate i not allocated to incoming truck k

n - total number of receiving gates

m - total number of consolidation zones

l - total number of trucks

Mathematical expression (5) defines the decision variable x_{ik} as binary. Inequity (6) prevents the total number of inbound trucks to exceed the total number of receiving

gates. This in fact wouldn't be an issue, since in such situation a queue is created.

3.3 Empirical Solution of the Problem

Empirical solution the company normally applies is based on a simple principle that the inbound truck that has the greatest number of pallets for a particular consolidation zone, gets the receiving gate closest to that zone. The truck with the second greatest number of pallets for a particular consolidation zone gets the next receiving gate closest to that zone, unless the gate is already allocated. Then it gets the second closest gate and so on. It is somewhat alike the Clarke & Wright's Savings Algorithm (1964), although in the company they are not aware of that.

The value of the objective function, calculated with the empirical solution in MS Excel spreadsheet, is shown in Fig. 3.

	INPUT DATA												
	Number of pallets q_{kj}				Total								
Truck	Zone 1	Zone 2	Zone 3	Zone 4	pallets								
1	6	12	4	11	33								
2	9	10	8	6	33								
3	14	6	9	4	33								
4	8	9	11	5	33	*Objective Function:*			min F =	285			
	Unit Manhattan Distance d_{ij}				$\sum q_{kj}d_{ij}$				x_{ik}				
From/To	Zone 1	Zone 2	Zone 3	Zone 4	Truck 1	Truck 2	Truck 3	Truck 4	Truck 1	Truck 2	Truck 3	Truck 4	$\sum x_{ki}$
Gate 1	1	2	3	4	86	77	69	79			1		1
Gate 2	2	1	2	3	65	62	64	62	1				1
Gate 3	3	2	1	2	68	67	71	63				1	1
Gate 4	4	3	2	1	79	88	96	86		1			1
								$\sum x_{ki}$	1	1	1	1	

Figure 3 Empirical solution

In compliance to the a.m. empirical solving principle, Gate 1 is allocated to Truck 3, Gate 2 is allocated to Truck 1, Gate 3 is allocated to Truck 4 and Gate 4 is allocated to Truck 2. This solution of the receiving gates allocation yields the objective function value of 285 (non-dimensional value).

3.4 Optimal Solution of the Problem

The optimal solution (Fig. 4) of the same problem is obtained by optimizing the mathematical model of the problem, using MS Excel spreadsheet optimizer Solver.

	INPUT DATA												
	Number of pallets q_{kj}				Total								
Truck	Zone 1	Zone 2	Zone 3	Zone 4	pallets								
1	6	12	4	11	33								
2	9	10	8	6	33								
3	14	6	9	4	33								
4	8	9	11	5	33	*Objective Function:*			min F =	273			
	Unit Manhattan Distance d_{ij}				$\sum q_{kj}d_{ij}$				x_{ik}				
From/To	Zone 1	Zone 2	Zone 3	Zone 4	Truck 1	Truck 2	Truck 3	Truck 4	Truck 1	Truck 2	Truck 3	Truck 4	$\sum x_{ki}$
Gate 1	1	2	3	4	86	77	69	79			1		1
Gate 2	2	1	2	3	65	62	64	62		1			1
Gate 3	3	2	1	2	68	67	71	63				1	1
Gate 4	4	3	2	1	79	88	96	86	1				1
								$\sum x_{ki}$	1	1	1	1	

Figure 4 Optimal solution of the problem

In the optimal solution, Gate 1 is allocated to Truck 3, Gate 2 is allocated to Truck 2, Gate 3 is allocated to Truck 4 and Gate 4 is allocated to Truck 1. This solution of the receiving gates allocation yields the objective function value of 273 (non-dimensional value).

4 SIMULATION MODEL AND RUNNING SIMULATION EXPERIMENTS

Since the values of the mathematical model objective function are non-dimensional values, while the improvement should be quantified in units of time, as the key performance indicator (KPI), the simulation model of inbound cross docking operations is designed, by using Arena simulation software. Arena is a discrete event simulation software developed by Rockwell Automation Inc. Discrete event simulation describes a process with a set of unique, specific events in time. It is designed for analysing the impact of changes involving significant redesigns associated with supply chain, manufacturing, logistics, distribution, warehousing and service systems.

The input data for the model are durations of the inbound cross docking operations, which are continuous stochastic variables. In order to determine the statistical distribution of the duration times, a representative sample is needed.

For this purpose, the inbound cross docking operations were scanned during February 2021 and 100 records of each movement were made. Due to limited resources, certain approximations have been introduced, but that is irrelevant for the main objective of this article.

Based on the empirical data, theoretical functions of probability distributions are determined, by using Arena Input Analyser software tool. The input data analysis resulted by selecting normal distribution of the cross docking operations duration times, as shown in Fig. 5.

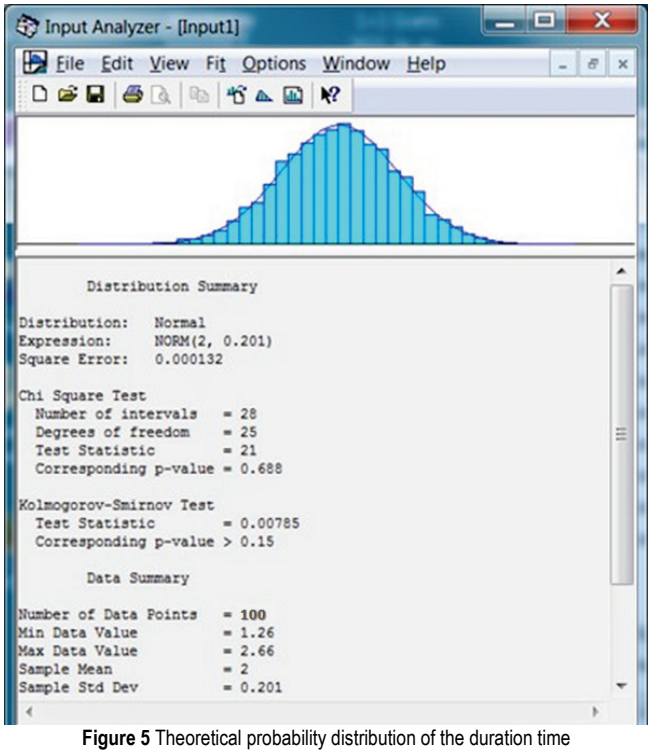


Figure 5 Theoretical probability distribution of the duration time

The distribution shown in Fig. 5 refers to movements from a receiving gate to the closest consolidation zone (e.g. Move from Gate 1 to Consolidation Zone 1) and is

considered a unit time. Analogously to the Manhattan Distance calculation, durations of movements in other combinations Gate - Zone are listed in the Tab. 1.

Table 1 Duration times of the inbound cross docking operations

Operation (Gate - Zone)	Probability Distribution	Mean (minute)	Standard deviation (minute)
Move 1, 1	Normal	2	0.201
Move 1, 2	Normal	3	0.201
Move 1, 3	Normal	4	0.201
Move 1, 4	Normal	5	0.201
Move *i*, *j*	Normal	…	0.201
Move …	Normal	…	0.201
Move *n*, *m*	Normal	2	0.201

With reference to the principle of determining the cross docking operations duration times illustrated in the Tab. 1, the actual duration times generated in the simulation experiments are shown in the Fig. 6.

The key performance indicator (KPI) refers to the average time needed to move one pallet from the gate to the respective consolidation zone.

Two simulation experiments, with the same input data are performed, first with the empirical solution the company normally use and the second with the optimized solution obtained from the linear programming mathematical model.

Time per Entity

VA Time Per Entity	Average	Half Width	Minimum Value	Maximum Value
Move 11	1.9809	(Insufficient)	1.6863	2.3889
Move 12	3.0188	(Insufficient)	2.8838	3.2575
Move 13	4.0850	(Insufficient)	3.7764	4.3115
Move 14	5.0907	(Insufficient)	4.7589	5.3055
Move 21	3.1603	(Insufficient)	2.8820	3.5047
Move 22	1.9993	(Insufficient)	1.6983	2.2504
Move 23	3.1324	(Insufficient)	2.8860	3.3447
Move 24	3.9129	(Insufficient)	3.4525	4.1800
Move 31	4.0321	(Insufficient)	3.7462	4.4033
Move 32	3.1736	(Insufficient)	3.0628	3.3031
Move 33	1.9427	(Insufficient)	1.5517	2.2864
Move 34	2.9198	(Insufficient)	2.6234	3.1254
Move 41	4.9925	(Insufficient)	4.5248	5.4973
Move 42	2.9400	(Insufficient)	2.5340	3.2010
Move 43	3.0656	(Insufficient)	2.9712	3.1975
Move 44	2.0982	(Insufficient)	1.8300	2.3185

Figure 6 Duration times in the simulation experiments

4.1 Simulation Experiment with the Empirical Solution

Process flow of the simulation model with the empirical receiving gates allocation is shown in Fig. 7.

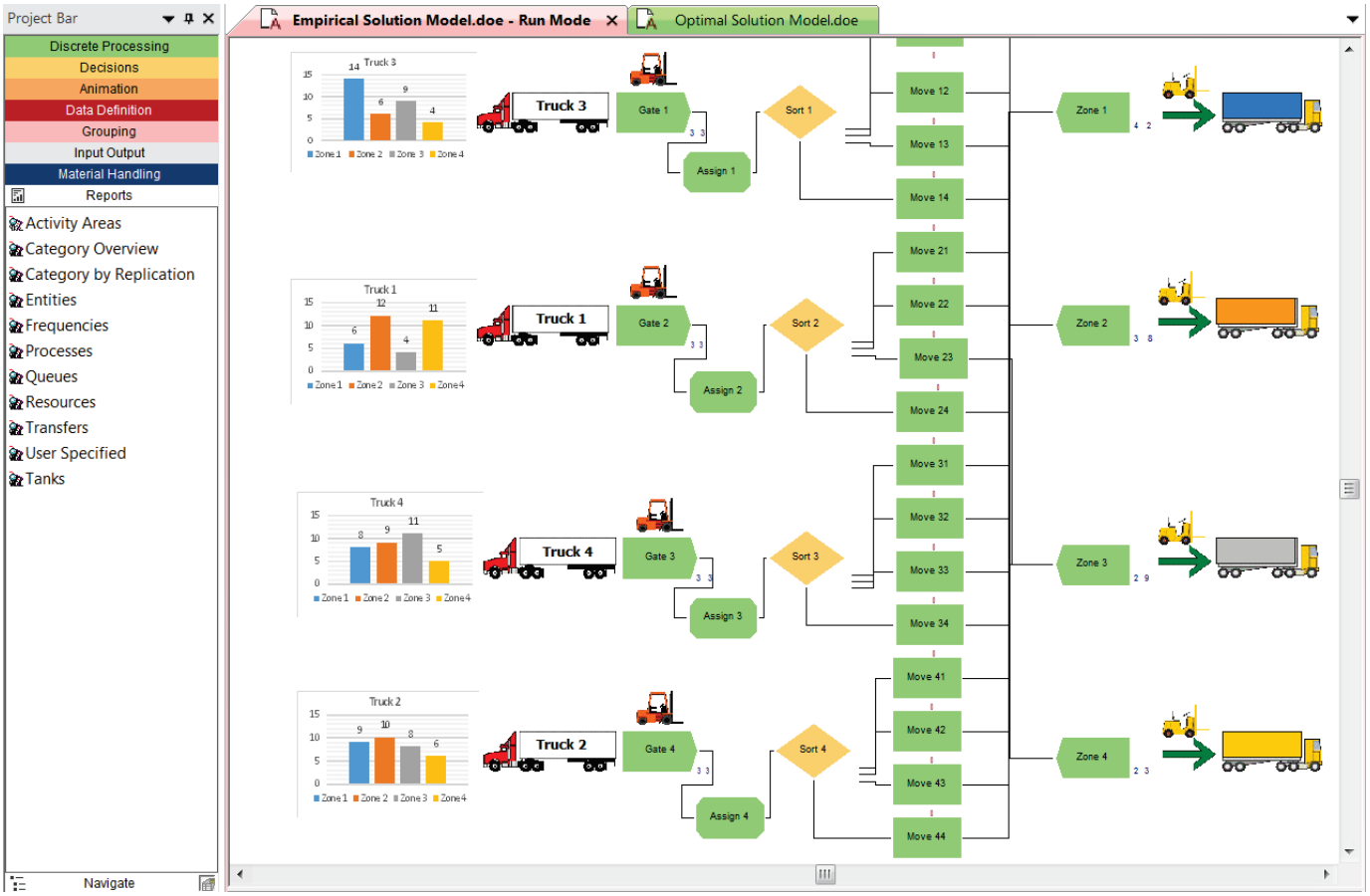


Figure 7 Process flow of the simulation model with the empirical receiving gates allocation

The value of the key performance indicator (KPI) obtained by the simulation experiment with the empirical receiving gates allocation is 3.30 minutes per pallet (the data generated in the Arena simulation reports).

4.2 Simulation Experiment with the Optimal Solution

Process flow of the simulation model with the optimal receiving gates allocation is shown in Fig. 8.

The value of the key performance indicator (KPI) obtained by the simulation experiment with the optimal receiving gates allocation is 3.16 minutes per pallet (the data generated in the Arena simulation reports).

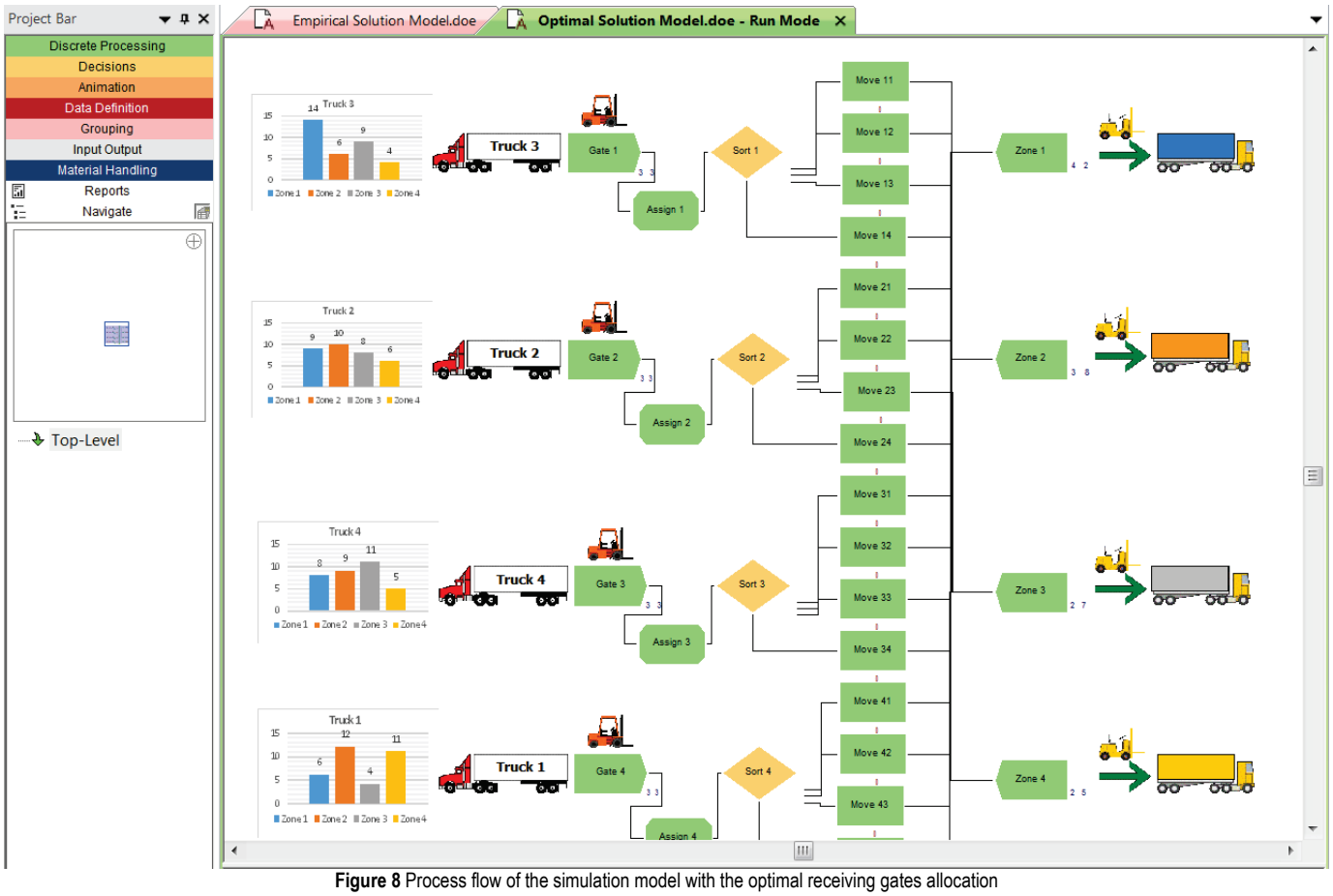


Figure 8 Process flow of the simulation model with the optimal receiving gates allocation

5 DISCUSSION OF THE RESULTS

The improvements in performances of the inbound cross docking operations, achieved by optimizing the receiving gates allocation, are listed in the Tab. 2.

Table 2 Improvements achieved by optimization

OPTIMIZATION MODEL		SIMULATION MODEL	
	Objective function value	Minutes per pallet	Total minutes
Empirical	285	3.30	436.06
Optimal	273	3.16	417.07
Reduction	**4.2%**	**4.4%**	**18.99**

The improvement on the optimization model (linear programming mathematical model) is quantified as the difference between the value of the objective function in case of the empirical receiving gates allocation (285) and the value in case of the optimal gates allocation (273).

Since the values are non-dimensional, only the percentage reduction (4.2%) may be referred as the improvement achieved, although it still cannot be expressed in any physical dimension (weight, time, distance or so).

The results of the simulation experiments enable comparing processing time (average duration of inbound cross docking operations) as the KPI required.

The KPI value in the experiment with the empirical receiving gates allocation is 3.30 minutes per pallet and the total time to process all pallets unloaded from all four inbound trucks (132 pallets) is 436.06 minutes.

The KPI value in the experiment with the optimal receiving gates allocation is 3.16 minutes per pallet and the total time to process all pallets unloaded from all four inbound trucks (132 pallets) is 417.07 minutes.

Therefore, the improvement is quantified in minutes, as the reduction of processing time achieved by optimization of the receiving gates allocation: 4.4% or 18.99 minutes for processing all 132 pallets.

Academic version of the Arena simulation software is limited to the maximum of 150 entities, which are pallets in this model. Because of this limitation, only four receiving gates could have been encompassed by the model. Each gate is allocated to one truck, therefore receives 33 pallets, which means a total of 132 pallets are generated out of four receiving gates. Each additional gate would generate 33 pallets more, which would exceed the limit of 150 entities.

6 CONCLUSION

Optimal receiving gates allocation enables minimizing the quantity of goods moved and the distances passed by the

forklifts in the XD terminal, thus reduces working hours and the duration of the cross docking operations. Due to the simplicity of use, flexibility and fast problem solving, the optimization by linear programming mathematical model is suited for daily use in real situations, even when deviations in schedule of trucks arrivals occur.

However, the inability to quantify the improvement achieved by the optimization in physical dimensions (weight, time, distance, or so), may be a major disadvantage in presenting the actual benefits to the stakeholders of the system being optimized.

In order to quantify the benefits achieved by the optimization in units of time, as the required key performance indicator (KPI), the simulation model of inbound cross docking operations is designed, and two simulation experiments are performed. First with the empirical receiving gates allocation and the second with the optimized receiving gates allocation, obtained from the linear programming mathematical model.

This way, the simulation modelling enables not only quantifying benefits of the optimization in physically measurable values, but also verifying the mathematical model.

7 REFERENCES

[1] Goddefroy, N. & Mellaerts, A. (2013). Optimizing the Dock Door Assignment Problem in Cross-Docking Warehouses. *Master Thesis*, Universiteit Gent, Faculteit Economie en Bedrijfskunde.

[2] Babić, D., Stanković, R., & Bajor, I. (2020). *Špediterski poslovi u logističkoj djelatnosti*. Fakultet prometih znanosti, Zagreb. (in Croatian)

[3] Yu, V. F., Sharma, D., & Murty, K. G. (2008). Door Allocations to Origins and Destinations at Less-than-Truckload Trucking terminals. *Journal of Industrial and Systems Engineering, 2*(1), 1-15.

[4] Stanković, R., Šafran, M., & Božić, D. (2016). Guidelines for Improving Logistic Performances as Drivers of the Logistic Industry Development. *Tehnički vjesnik - Technical Gazette, 23*(5), 1497-1503. https://doi.org/10.17559/TV-20141016184435

[5] See https://www.joachimdespland.com%2Fmammoth.html

[6] Đurić, N., Stanković, R., & Pašagić Škrinjar, J. (2015). Optimizing the Cross-Dock Door Assignment by Applying Mathematical Model. *International Scientific Conference ZIRP 2015*, Zagreb.

Authors' contacts:

Ratko Stanković, PhD
Faculty of Transport and Traffic Sciences,
University of Zagreb,
ZUK Borongaj,
Borongajska cesta 83A, HR-10000 Zagreb, Croatia
ratko.stankovic@fpz.hr

Diana Božić, PhD
Faculty of Transport and Traffic Sciences,
University of Zagreb,
ZUK Borongaj,
Borongajska cesta 83A, HR-10000 Zagreb, Croatia
diana.bozic@fpz.hr

ISSN 1846-6168 (Print), ISSN 1848-5588 (Online)
https://doi.org/10.31803/tg-20210805121228

Preliminary communication

Supply Chain Management in Pandemic Times: An Experience from Macedonian Automotive Industry

Atanas Kochov*, Elena Kochovska

Abstract: The automotive industry is one of the sectors that has been hardest hit by the pandemic crisis. The pandemic's effects have resulted in multiple disorders, which led to loss of important suppliers and the inability to obtain vital parts, exposing the vulnerability of current Lean Just in Time supply chains. This paper provides a brief analysis of the COVID-19 pandemic's impact on the automotive sector in the Republic of North Macedonia. The provided findings are based on a research study conducted simultaneously in eight automotive organizations in the Republic of North Macedonia. This study sought to investigate the extent of the pandemic's influence on organizations' supply chains, what preventive steps have been implemented to minimize the virus's transmission, and what are the most prevalent obstacles that organizations have experienced during the pandemic.

Keywords: automotive industry; pandemic; supply chain

1 INTRODUCTION

Following the initial COVID-19 outbreak in early 2020, concerns about a destabilization in Chinese parts exports quickly transitioned into massive manufacturing disruptions across Europe, as well as the world's other industrial leaders. As the coronavirus spread from China, the world's second-largest economy, to the other countries in Asia, Europe, the Americas, and the Middle East, the global economy and international markets suffered. [1] Policies aimed at preventing the virus's spread, such as travel restrictions and quarantines, have had the unfortunate effect of disrupting international supply chains, restricting business operations, and decreasing revenues.

Due to the rapid spread of COVID-19 throughout the world, on March 11, 2020 the World Health Organization declared it as a pandemic. [2] Countries around the world have also been shutting down their economies in order to slow the spread of the disease and avoid overcrowding in hospitals. Closing borders was also one of the first defensive measures implemented. As a result, the movement of goods and materials was temporarily suspended. In such a situation, the normal operation of even more organizations' supply chains around the world becomes a significant challenge.

COVID-19 has had a rapid and significant impact on today's integrated automotive sector and has presented unexpected challenges to the entire automotive supply chain. The first shock was caused by containment measures designed to slow the rate of infection. These measures explicitly reduced output by keeping workers away from work. Supply-chain contagion also amplified immediate supply shocks as manufacturing sectors in less-affected countries found it more difficult and/or expensive to obtain necessary imported industrial inputs from hard-hit nations, and then from each other. [3]

The pandemic caused by the coronavirus is still disrupting social and human interactions, while also having a significant impact on complex, global production networks. Waves of localized outbreaks, regional or national blockages, and ongoing supply and demand disruptions continue to present organizations with new and unexpected challenges that must be addressed by making adjustments on their business operations in order to maintain and protect their supply chains.

In accordance with the discussion above, the aim of this research is to provide critical insights and identify the most critical barriers into the reactions of Macedonian automotive companies and lessons learned in relation to the COVID-19 pandemic. To begin, as far as the authors are aware, this is the first preliminary study that looks specifically at the possible consequences of COVID-19 for the automotive sector in the Republic of North Macedonia.

Second, the paper aims to present the immediate actions of primarily organizational decisions made by automotive companies, taking into account the complexity of the automotive sector's real-world responses and their impact on supply chain resilience. The rest of this paper is organized as follows: Section 2 provides insights and explains the significance of the automotive industry in the Republic of North Macedonia.

Following that is a description of the research methodology. Section 4 presents the findings based on the data analysis of the results from the questionnaires. The authors reach the conclusion by summarizing the key points and emphasizing the study's limitations, as well as making recommendations for future research.

2 AUTOMOTIVE INDUSTRY IN NORTH MACEDONIA

The automotive industry is absolutely essential to the Macedonian economy, both in terms of exports and the number of jobs it provides. The high quality products manufactured in these factories in accordance with the highest automotive standards ensure that the Macedonian automotive component production is ready for export. The latest reports state that the automotive sector employs over 28000 people, while also provides the largest number of newly created jobs in the last 3 years compared to any other sector in the economy. In the period 2017-2019, more than 16,000 employees were created in the automotive industry, which shows that this industry is reaching its greatest progress in recent years. [4]

In addition, according to the recent data from the State Statistical Office, 65% of the country's total exports in

January 2021 were made by companies in the automotive industry.

The country's auto parts manufacturing companies are heavily integrated into the European automotive industry's supply chains. These are companies that are primarily export-oriented and account for a significant portion of the country's exports. In the last few years, the Macedonian economy has become much more deeply integrated into global supply chains through these companies for the production of automotive parts, but it has also completely changed the export structure, particularly in favor of products with higher technological finishing.

As the European car industry was heavily affected by the pandemic and decreasing demand for automobiles, the high concentration of exports to this industry resulted in a sharp drop in exports. The significant decline in the number of companies in this industry has a negative impact on the Macedonian economy and employment. The Macedonian economy has been experiencing extremely difficult times in the past period because of the negative impact of the global pandemic's health and economic crisis.

In 2020, the economy contracted by 4.5%, with a 10% drop in exports, as well as a drop in industrial production and employment. Many businesses were affected by the crisis, and the period of stabilization will last longer because the development dynamics of some businesses in the post-crisis period will be delayed. As a result, the companies in this industry have appealed to all state institutions to take a serious approach to supporting this industry in order to overcome this challenging situation without major layoffs. [5]

3 RESEARCH METHODOLOGY

Comparative method was used for conducting this research. Data collection was performed by using questionnaire surveys. The flexibility provided by the survey process, which can be used to obtain a large number of different types of information at the same time, is the main advantage of this way of gathering information. [6] The survey conducted through an electronic questionnaire significantly reduces the costs and time required to conduct the survey. Additionally, at a time when employee health is a priority, online questionnaire surveys provide a safe, risk-free environment for interaction.

The process of planning and preparing the questionnaire is of great importance in this way of gathering information. When developing the questions, special care was taken to ask clear and understandable questions that are not ambiguous or suggestive. Moreover, it was essential for the questionnaire to ensure the anonymity of all respondents, which would result in greater objectivity of the results.

The first section of the questionnaire asked general questions about the respondent, such as their current position in the organization and their experience in the automotive industry. The main part of the questionnaire, consisting of 6 questions, aimed to determine the impact of the COVID-19 pandemic on the organization's supply chain, what preventive measures have been taken to deal with the spread of the virus, and what were the most common challenges that organizations have faced in the past period. The third part included 15 separate statements and each of the statements was answered within the offered answers: I completely disagree (1 point), I do not agree (2 points), I neither agree nor disagree I agree (3 points), I agree (4 points), I completely agree (5 points).

Before distributing the survey to respondents, a pilot survey was conducted as part of the questionnaire development process. This pilot survey was used to change and eliminate variables. Academics and industry experts were also consulted. Although no changes to the questionnaire were made during this phase, it was necessary to obtain approval that the questionnaire was understandable and acceptable for data collection.

The survey was conducted during May 2021, and according to all recommendations for working in conditions of COVID 19 pandemic. Respondents from eight different companies in the automotive sector in Republic of North Macedonia contributed to answering this survey questionnaire. The automotive companies involved in this study are all considered to be belong to the category of large enterprises. According to the State Statistical Office of North Macedonia, large enterprises are those companies that have full time employees more than 251. The automotive companies who were involved in this study ranged from 300 employees to 6500 employees. The total number of employees in the companies included in the study is 12630.

The questionnaire was developed on the Google Forms platform and all respondents answered it online. For a better overview of the obtained results, they are presented in tabular or graphical form

The initial invitation to participate in the survey was sent to contact persons from 10 different automotive companies. A total of 8 positive responses were recieved, while the remaining 2 stated that they can't participate and provide the requested information. To the companies who chose to participate in the survey, an online link was provided, who was later distributed to the employees who fit our target categories (managers, team leaders, supervisors). When analyzing the recieved responses, first all responses from each company were summed up and later analyzed at group level by having one average answer per company.

A qualitative analysis of the results was used to analyze the complex phenomena and concepts of the research, as well as the topics listed as key in the thesis. Quality instruments should lead to an introduction and explanation of the problems, an understanding of the differences between the various strategies used to reduce disruption levels, as well as a description of the experiences, benefits, and challenges that occured during the pandemic.

4 RESULTS AND DISCUSSIONS

4.1 Respondent and Company Profile

The first aspects to be investigated were the general background of the respondents such as the job position and years of employment in the company. The sample of respondents to the survey questionnaire included employees from different areas in the organizations and from different levels of the hierarchy: managers, production leaders, planners, but for the most part they were coordinators and leaders for continuous improvement. Most respondents

(75%) stated they have between five and ten years of experience in the automotive industry. Regarding the quality system certification, all respondent companies have at least one certification in the relevant field. Over 90% of respondents said their organization uses the ISO 9001 standard, a quality management system standard. Additionally, more than two-thirds use ISO 14001, the environmental protection system standard. Other types of quality certification such as ISO 13053, ISO 45001 and ISO 5001 were owned by 8% of respondent companies respectively.

4.2 Data Analysis

At a time when employee health is prioritized, in addition to mandatory measures imposed by the government, many organizations are also forced to close their facilities or work with a reduced number of employees in order to meet the requirements to customers in a timely and quality manner. In this questionnaire, respondents were asked what precautions their organizations had taken to protect their health and prevent the spread of the virus. Fig. 1 depicts the results.

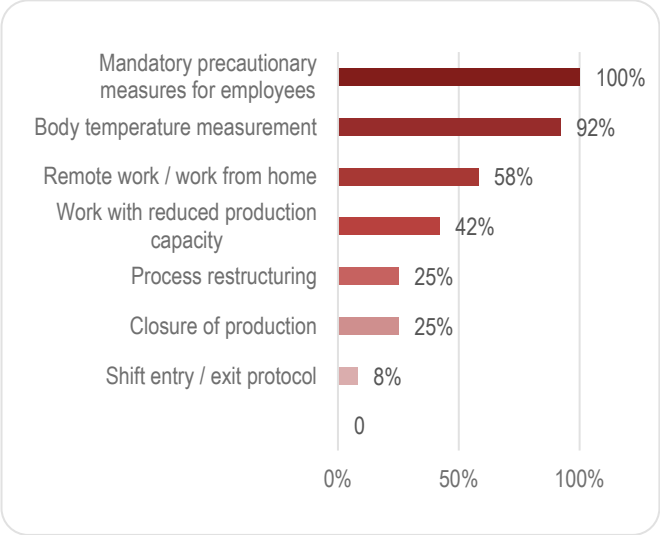


Figure 1 Responses to question: What preventive measures has your organization taken to deal with the spread of COVID 19?

While supply chain disruptions have a negative impact on the overall functioning of the organizations, some sectors within the companies have been more severely affected than the others.

According to the responders of this questionnaire, the disruption in Sources and Procurement was the source of the most significant challenges. Procurement is the process of acquiring goods, inputs, and materials that an organization requires for its operational activities, whereas sourcing is the process of establishing and maintaining vendor relationships, vetting suppliers, and developing and maintaining a supply chain of vendors who are ideal for the needs of the organization. Both processes involve dependence on other third entities, so in times when this third companies are also affected by the pandemic and have disruptions in the way they function themselves, it's clearly how this can cause the biggest challenge. Following that are the difficulties in managing International Logistics and Transportation, as well as Supply Chain Planning. The closure of borders, as well as other pandemic-related disruptions in the normal movement of products across the world were resulting in record-high freight prices and perhaps increasing costs of transportation damage. According to certain studies the pandemic has a statistically negative and significant influence on air and land freight, while it has a statistically inconsequential effect on ocean freight. [7] In addition, although the supplier capacity is not directly conected to the supply chain, by monitoring and proactively minimizing supplier capacity risks, supplier capacity management helps companies in preparing for unavoidable interruptions.

The total results are presenend on Fig. 2.

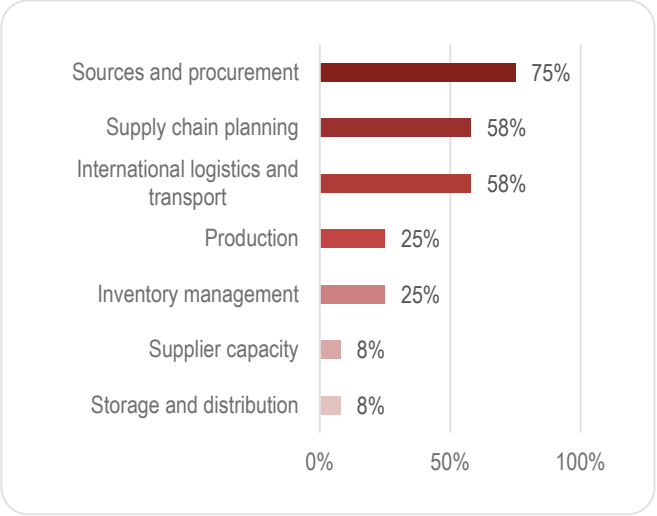


Figure 2 Responses to question: Which areas of your supply chain were most affected by the COVID-19 pandemic?

Although it is used to improve production efficiency and flexibility, the "just-in-time" inventory model - which keeps only the minimum additional inventory required to meet customer demand - is a process that is vulnerable when subjected to high operating stress caused by a crisis [8].

The challenges that organizations have had to face are numerous, but according to the sample of respondents to this questionnaire, the majority of the organizations have had to deal with delayed or canceled orders, both from suppliers and to customers. Fig. 3 portrays the other challenges listed by the respondents.

The challenge for organizations is to strengthen their supply chains without jeopardizing their competitiveness. To meet that challenge, managers must first understand their vulnerabilities before considering a number of steps, some of which should have been taken long before the pandemic struck. A year after the beginning of the challenges posed by COVID-19, over half of the sample respondents stated that their organizations had already recovered from the disruptions caused by the pandemic. Fig. 4 displays the

organizational division based on the current situation and the phase of response to disruptions.

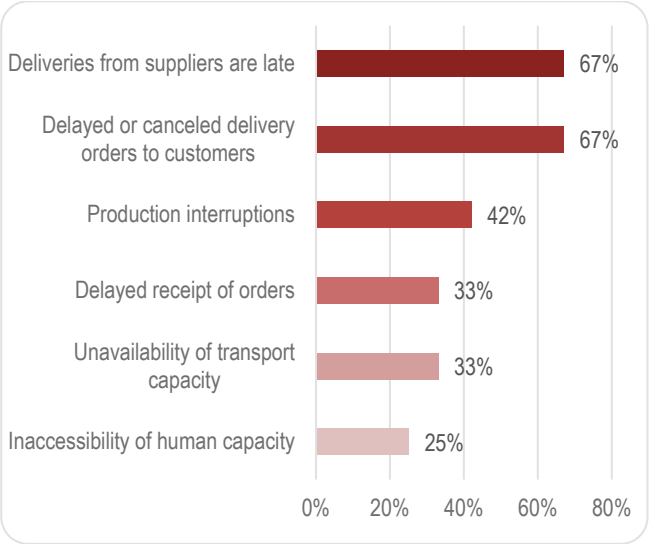


Figure 3 Responses to question: What are the most common challenges your organization faced during the COVID 19 pandemic?

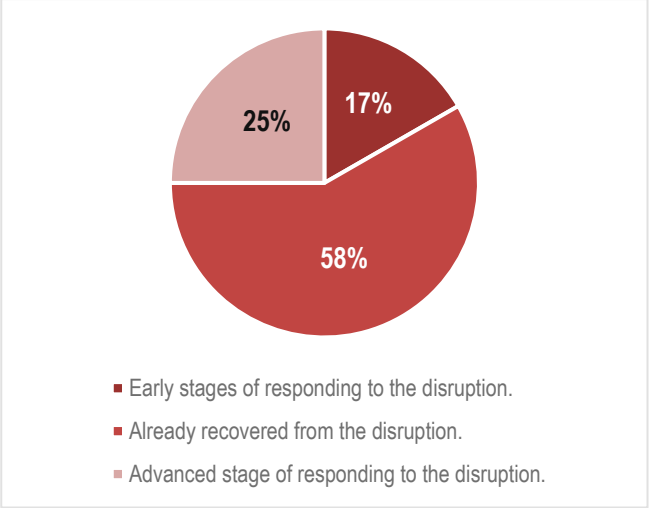


Figure 4 Responses to question: What is the current state of your supply chain in relation to COVID 19?

Once the immediate supply chain risks have been identified, leaders must design a resilient supply chain for the future. This begins using scenario analysis to assess the structural resilience of critical logistics nodes, routes, and modes of transportation, followed by the risk assessment task, the constant updating of risk impact assessments, remediation strategies, and risk management oversight. Processes and tools developed during the crisis management period should be formalized. Stronger collaboration with suppliers can help to strengthen a supplier's entire ecosystem over time, resulting in greater resilience. According to the sample of respondents to this questionnaire, the necessary reinforcements mostly refer exactly to the level of preparedness, planning and risk management.

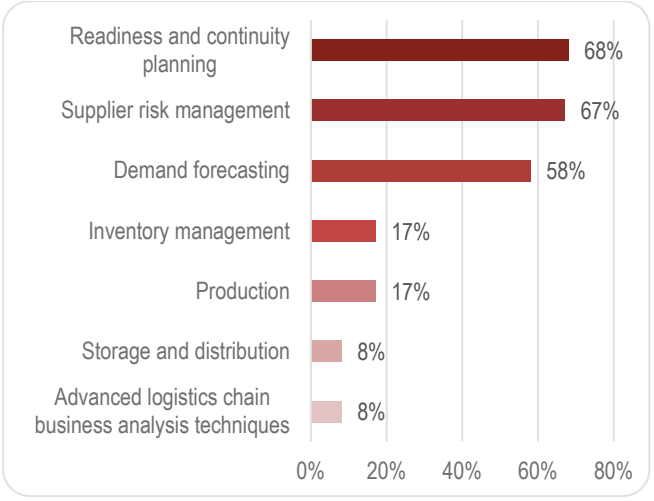


Figure 5 Responses to question: Which areas need changes to strengthen the supply chain of the future disorder?

As more organizations rely on global suppliers from China or other locations affected by COVID-19, supply chain continuity activities are critical. This huge supply disruption highlights the importance of creating or updating business continuity plans that identify key and secondary suppliers as well as alternative resources. A company's ability to quickly and effectively respond to interruptions can be improved by identifying and contracting with vendors and other providers prior to a crisis, where applicable. As evidenced by the ongoing pandemic, organizations must carefully and constantly analyze the impact of new threats on their existing processes and their supply chain business continuity plan reaction. The essential phases in risk management are identifying business interruption risks, evaluating the possible implications on the company, devising mitigation solutions, and preplanning ahead of a circumstance like COVID-19. Companies will be best positioned to tackle the challenges ahead and prosper in the long run if they take steps to stabilize supply chain operations and execute business continuity strategies.

5 CONCLUSION

The goal of this paper was to investigate the COVID-19 pandemic's impact on the Macedonian automotive industry. The authors used a research approach based on primary data from questionnaire surveys to gain an understanding of the implications and reactions.

A very encouraging finding was that almost 60% of the respondents' companies had already recovered from the pandemic's disruptions. While black swan events like the coronavirus cannot always be forecasted, the ability to understand supply chain risks and opportunities allows organizations to plan ahead while maintaining customer relationships in times of crisis. The authors also discovered that the most common issue they have encountered were late or cancelled deliveries from both from their suppliers and to their customers. The analysis results also revealed that the most improvements are necessary in the areas of preparedness and planning. The majority of the respondents'

companies faced similar challenges and took similar actions, according to the findings of this study.

The authors are confident that their approach produced interesting and valid results in the context of COVID-19, but the authors are also hesitant to generalize the findings. The sample size of eight companies is not only small, but the authors also limited the research to a single industry. Also in order to improve and enrichen the research findings, it is also necessary to improve and strengthen the collaboration between the academic institutions and the companies from the specific industry, as well as develop new motivational methodologies for future collaboration. As a result, the authors encourage future studies to expand the sample size and diversify the respondents' industrial sectors, resulting in unique and complementary insights.

Notice

The paper was presented at MOTSP 2021 – 12th International Conference Management of Technology – Step to Sustainable Production, which took place in Poreč/Porenzo, Istria (Croatia), on September 8–10, 2021. The paper will not be published anywhere else.

6 REFERENCES

[1] Pisch, F. (2020). Just-in-time supply chains after the Covid-19 crisis. https://voxeu.org/article/just-time-supply-chains-after-covid-19-crisis

[2] WHO Director-General's opening remarks at the media briefing on COVID19 -March 2020

[3] Baldwin, R. & Freeman, R. (2020). Supply chain contagion waves: Thinking ahead on manufacturing 'contagion and reinfection' from the COVID concussion. https://voxeu.org/article/covid-concussion-and-supply-chain-contagion-waves

[4] … (2020). Invest North Macedonia-Official Government Agency for Investment and Export Promotion. https://investnorthmacedonia.gov.mk/mk

[5] … (2020). Short-term Economic Trends - Ministry of Finance of North Macedonia.

[6] Nayak, M. S. D. P. & Narayan, K. A. (2019). Strengths and weakness of online surveys. *IOSR Journal of Humanities and Social Science, 24*(5), 31-38.

[7] X., Yanling, J.-P., Li, C.-C., Chu, & Dinca, G. (2021). Impact of COVID-19 on transportation and logistics: a case of China. *Economic Research-Ekonomska Istraživanja*, 1-19. https://doi.org/10.1080/1331677X.2021.1947339

[8] Bryce, C., Ring, P., Ashby, S., & Wardman, J. (2020). Resilience in the face of uncertainty: early lessons from the COVID-19 pandemic. *Journal of Risk Research, 23*(7-8), 880-887. https://doi.org/10.1080/13669877.2020.1756379

Authors' contacts:

Atanas Kochov, Prof. dr.
Ss. Cyril and Methodius University in Skopje,
Faculty of Mechanical Engineering – Skopje,
Karposh II bb, 1000 Skopje, Republic of North Macedonia
+389 71-299-299,
atanas.kochov@mf.edu.mk

Elena Kochovska, MSc student
Ss. Cyril and Methodius University in Skopje,
Faculty of Mechanical Engineering – Skopje,
Karposh II bb, 1000 Skopje, Republic of North Macedonia
+389 78-517-170,
kochovska@hotmail.com

ISSN 1846-6168 (Print), ISSN 1848-5588 (Online)
https://doi.org/10.31803/tg-20201015132216

Subject review

Sensors and Their Application in Precision Agriculture

Mladen Jurišić*, Ivan Plaščak, Željko Barač, Dorijan Radočaj, Domagoj Zimmer

Abstract: The paper depicts sensors in precision agriculture. It encompasses the most significant and frequently used sensors in agriculture. Furthermore, the paper explains the main sensor types according to their design, the recorded range of electromagnetic spectrum, as well as the way of detection, recording, measuring, and representation of the detected energy. The development of remote research has provided deeper understanding of remote sensors and their advantages. The sensors installed on soil testing equipment, fertilizing and crop protection machinery, as well as crop picking machinery have been analyzed relative to precision farming. The paper depicts widely known sensors *OptRx, ISARIA* and VRT technology. The results of the paper assess the data collected by sensors and processed in order to produce maps for agrotechnical operations. The application of maps decreases the employment of human resources, heightens the capacity of data collection, increases the precision of agricultural activities, and finally results in decreasing the cost of final products. The technological progress over the past decade has enabled the development of technology with variable application standards (*VRT*) that, according to current needs, enables input optimization.

Keywords: GIS; maps; precision agriculuture; sensors

1 INTRODUCTION

The basic aim of precision agriculture is to increase the quantity of accurate real-time data that can be deployed by farmers for decision making [1, 2]. Precision agriculture saves time and financial means, and improves crop yield and its quality [3-8]. The authors [9] state that precision farming also serves to improve ecological improvements, reduce environmental burdens and encourage naturally spatial conditions and improve production process documentation. The contemporary agriculture machinery is already equipped with sophisticated technology so the machine operator can get a direct and prompt insight into the farming area, monitor plant development and assess soil conditions [10]. In the future, almost all agricultural farms will be able to use information technology such as the global positioning system (GPS), geographic information systems (GIS), as well as the technology of precision agriculture and navigation systems [11].

The application of various sensors establishes and records the real- time parameters of production processes. Using modern sensors it can causes of operational efficiency as well as inefficiency can be accurately determined [12, 13]. The implementation of precision agriculture has made possible due to the development of sensing technology. Also precision agriculture is possible with the mapping of variables pertaining to a specific agrotechnical operation such as ploughing, sowing, fertilizing, plant protection, and harvesting. The application of optical sensing results in significant savings that make agriculture more profitable [14, 15]. The sensors that facilitate a simple collection of spatial and meteorological data are the principal element of precision agriculture [16].

Depending on the method of the conversion of a physical measurand into measurement information there are: first, sensors using analogue converters; second, sensors using analogue converters for the conversion of analogue signals into a signal with a changeable period or frequency; and finally, sensors with analogue-digital converters [17]. The application of sensors in agricultural machinery, i.e. the use of machine vision, provides numerous information on soil condition, plants, pests, and weeds [18]. The data collected in that manner enable an optimal use of resources. The author [18] proposes that the farmers who utilize data in an efficient way will reach higher yields compared to those who do not engage in this practice. The authors [21, 22] state that sensors are part of key technologies that increase the overall productivity, such as GIS and GPS.

2 DIFFERENT SENSORS SYSTEMS

Navigating agricultural aggregates with different sensors such as yield and fuel sensors and similar installed in agricultural aggregates has enabled an accurate data distribution across the data processing area. Sensors are devices used to detect, record, and measure the radiation of electromagnetic energy, their own (emitted energy), as well as reflected energy. Sensors can be categorized according to their design, the registered range of electromagnetic spectrum, the way of detection, recording, measurement, and representation of the detected energy [23]. Sensors can record both wide and narrow spectral regions, individual spectral lines, i.e. the rays of the same wavelength or a series of separated spectral lines encompassing one spectral region. Since sensors are one of the principal components of contemporary electronic circuits and devices, they are frequently produced together with microprocessors to perform multiple functions. According to the type of the detected energy, sensors can be passive or active. The active sensors produce their own energy, send it to the object, and register the reflected radiation. Passive sensors, they just send and receive energy without producing energy. In remote readings, an active sensor is a device which transmits a light signal of a particular wavelength or an electron that is reflected off the target object carrying the data collected by the sensor through its reflection. Sensing technology is used in remote researches for remote measurements or the measurements of the occurrences that are invisible to the naked eye. Passive sensors detect energy emitted by the object itself regardless of whether the object has its own energy, or it transmits it. The main characteristics of sensors are sensitivity, linearity, precision, and resolution of signals.

Sensors convert a physical quantity into either analogue electrical or digital data. They react to conditions, which they convert into output signals [24]. The measurement of non-electrical signals starts with the conversion into the electrical ones and their subsequent processing. The conversion of nonelectrical quantity into an electrical signal requires energy coming from the domain of the signal or outside of it, which is facilitated through physical effects. Most measurement converters has three main parts: a sensor or a source of information; a measurement system or processor; and some kind of display for representation. Sensors use the energy emitted by a special source to create the data representing the measured quantity. The secondary element i.e. the processor processes the signals emitted by the sensor. The system of information representation is part of the measurement converter that produces the measurement output [25]. Agriculture sensors find their application in soil testing equipment, fertilizing and crop protection machinery, as well as crop harvesting machinery. The most frequent types of sensors in current use are electromagnetic and ultrasonic sensors. *LIDAR* and infrared sensors are currently in scientific investigation for agro-purpose. Electromagnetic sensors work on the principle of the dependence of inductance on changes in magnetic resistance. When a metal object gets closer, the magnetic resistance of the coil decrease while inductance increases. The parameters of electromagnetic flow and the characteristics of the object determine the region of detection by electromagnetic sensors. On the contrary, the working principle of inductive sensors is based on the change of magnetic resistance. The main advantages of inductive sensors are the following: resistance to water, oil, dirt, non-metal parts, object colour and roughness, impact, and vibration. Photoelectric sensors work on the principle of the change of parameters (optical signals) together with the changes of the measured physical data (occurrence of photoelectric effect). There are also some differences about the distance from the sensor to the crops. For example, the *SPAD* and the *ClorofiLOG* sensors need to make static measurements, touching the sensors on crop's leaves [26]. The working principle of thermoelectric sensors is based on the measurement of the temperature difference resulting in electric voltage. Their use are common in in biotechnology, medicine, the environment, and the agriculture [27, 28, 29]. Capacitive sensors rely on capacitivity to determine variable values. The change in the distance between surfaces impacts the change of capacitivity. This occurrence is utilized by capacitive sensors to identify the changes in object positioning. Accordingly, the sensor must be placed in the proximity of the observed object (0.25-2 mm). The inductive transducers include measurement tapes used to measure deformations, such as in statically and dynamically stressed constructions. One of the most common capacitive sensor used in precise agriculture for monitoring soil moisture content is *Field Connect* [30]. The working principle of potentiometer sensors is based on the changes of resistance due to changes in the sliding contact. The disadvantage of these sensors is the contact point between the slider and resistance wire. They are used to measure sensor resistance at close distances. Common use in agriculture is in following trajectory [31]. Ultrasound sensors are used to determine distance when the range of the obstacle is determined by the time necessary for the ultrasound to travel from the object as a reflected wave. According to the research done by the authors [32], ultrasound sensors (Fig. 1) can detect an object from 0.6 to 6 m with the minimal area of the object to be detected of 0,02 m^2. Their common use in agriculture is in spraying boom height control [30].

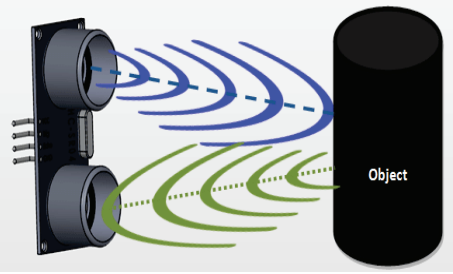


Figure 1 Ultrasonic sensor (Source: https://components101.com/ultrasonic-sensor-working-pinout-datasheet)

LIDAR optical sensors (Light Detection and Ranging) function on the principle of the change of parameters of optical signals in dependence on the change of a measurand. They deploy a measuring instrument that emits laser beams, which in turn, reflect off very tiny particles dispersed in the atmosphere (aerosols, cloud drops), and afterwards get registered by an optical receiver (Fig. 2). Optical sensors are applied in the contactless long-range detections. They are widely used since the object material is irrelevant [23].

Figure 2 LIDAR sensors-left (Source: https://velodynelidar.com/products/hdl-64e/), Infrared sensor-right (Source: https://ctgrow.com/vpd-sensors/25-vpx-3-vpd-infrared-sensor.html)

OptRX system is one of the most widely known sensor systems in agriculture. Sensors are mounted on an aggregate providing direct readings of crop condition and exerting a direct impact on agrotechnical operations. Additionally, *MSP3* is another well-known approach to the measurement of soil characteristics by sensors. The working principle of sensors is the same, whereas, unlike the former system, it requires processing of the collected data through a computer and mapping software. The data can result in various types of maps, which can be later used in agrotechnical operations [23]. Additionally, sensors are widely used by combine harvesters in annual harvesting. Combine yield sensors can be classified as systems for volume measurement, systems for power/impulse measurement, and other indirect measurement systems. Yield sensors deliver measurement values (grain diameter, grain flow, grain quantity), and for each harvested area (it represents the yield) equation calculations are performed [23]. The yield volume measurement system calculates the volume of the crop that flows past photosensors, which register and measure the time

of rays that are either let through or not. This period is calculated using a corresponding algorithm. The system's main disadvantage is the conspicuous inaccuracy of the data produced by measuring on sloping terrains. The systems for power/impulse measuring determine the mass against the time unit based on the power or impulse action of grains. Two finger-shaped sensors attached to a single power/impulse measuring unit are the main components of a sensor. Instead of the finger-shaped sensors, similar systems deploy electrical trackers and a spring plate for measuring the voltage change [23]. Apart from the mentioned systems, there are indirect measuring systems that deploy gamma rays shined towards the radiation detector by a weak source of radiation. Higher-quality sensors mounted on combine harvesters include microwave or infrared-NIR sensors (Near Infrared Reflectance). NIR sensors produce satisfactory results and are widely used for the measurement of moisture and protein content. NIR sensors are the basis for commonly used sensors in detecting plant disease and stresses [33]. For the crop protection is commonly using the application of variabale rate technology (VRT). The *VRT* use in field crops is based on the sensory approach to light reflection measuring from plants and the collected data analysis. By varying the luminous flux on the sensor, which depends on individual plant properties, an electronic signal is sent to the regulator which performs the dosing device opening and the particular medium's application [34]. According to [35] the plant sensor *PRO Active* has a growing impact on modern agricultural concepts. This sensor has been developed for daylight conditions. It consists of two sensor units and a reference sensor attached to the roof to measure the incidence light (the quantity of insolation). The sensor estimates the status of nitrogen and plant biomass. The data are used to calculate the optimal application level in real-time.

3 RESULTS AND DISCUSSION

The above discussed sensors generally deliver data when the machinery is in motion. Some information needs to be additionally processed through computers and mapping software. The processed data facilitate the creation of various types of maps for further use in agrotechnical operations. The obtained values in forms of dots provide the basis for all maps. The first maps of sensor collected values consisted solely of the measured values represented through dots. The measuring points are assigned the colour of the respective yield value. Fig. 3 depicts a dispersible yield map. Using the grid display, algorithms can be applied to create an isometric yield map with the aim of improving the characteristics of maps (Fig. 4). Isometric design improves the visual design; however, it is not applied in precision agriculture as it cannot be applied to the contemporary machinery. The results acquired by *MSP3* are read by *FieldFusion* software used for measurement of pH soil values (Fig. 5).

OptRx sensor uses the wavelengths of 670, 730, and 760 nm to calculate NDVI and NDRE. *OptRx* sensors are not sensitive to ambient lighting and can consequently be used both during the day and night-time. Additionally, they belong to few sensors that combine more than six values. A sensor must be able to discover crop stress (for crops such as potato and wheat) in early and later growth phases as well as to record exact VI values under the dusty field conditions. Plant growth significantly impacts the change of reflexion. Fig. 6 shows that it is necessary to change the red border in later growth phases and maintain the comparison of healthy against unhealthy plants when plant sensors read only the red light with the reflexion change being significant due to plant growth. The *OptRx* sensor manages this situation in the most reliable, practical and economical way on the market. The results show the relation between NDVI and NDRE and a kilogram of nitrogen per hectare (Fig. 7). The *OptRx* sensors have displayed their ability to discover crop stress, e.g. in potatoes and wheat, during the earlier and later growth phases. A major advantage of the *OptRx* sensors is the recording display of the exact value of VI in field conditions (Fig. 8).

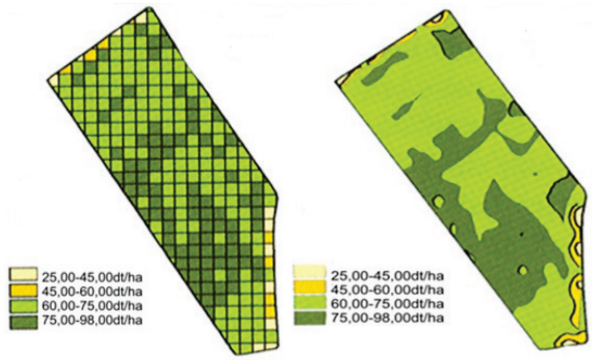


Figure 3 Scatter yield card-left, **Figure 4** Outline map of yields (Source: http://polj.savetodavstvo.vojvodina.gov.rs/sites/default/files/precpoljplascak.ppt)

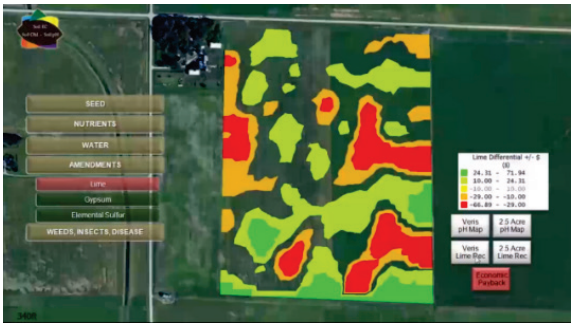


Figure 5 Example of soil pH measurement results (Source: https://veristech.com/the-solutions/fieldfusion%E2%84%A2)

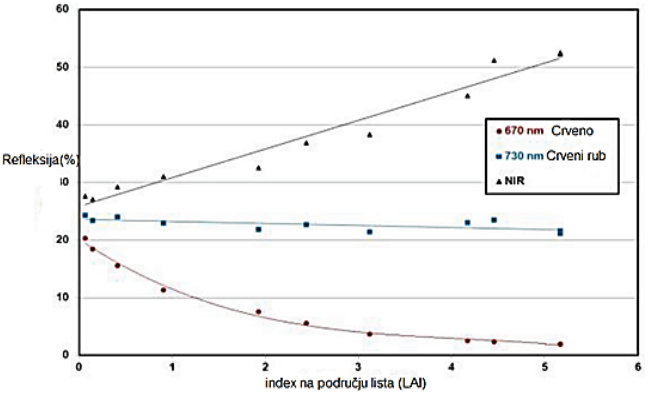


Figure 6 Reflection / Index diagram in the sheet area (Source: Hans Stiekema Ag Leader Europe)

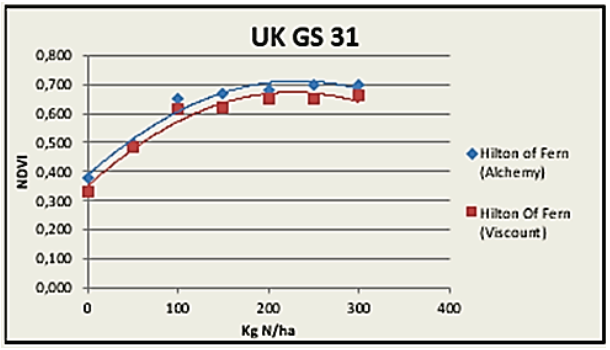


Figure 7 Diagram NDVI / kg nitrogen per hectare
(Source: http://www.findri.hr/agleader/download/OptRx_2012.pdf)

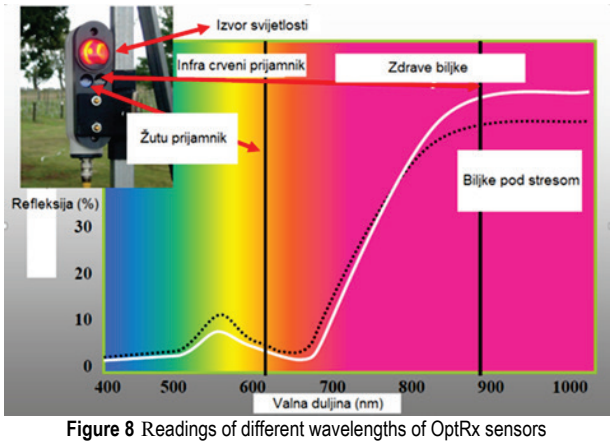


Figure 8 Readings of different wavelengths of OptRx sensors
(Source: Hans Stiekema Ag Leader Europe)

The advantage of the plant sensor *PRO Active* is the application of real-time relative to crop growth and without the atmospheric factors impact. The main working parameter is nitrogen (Fig. 9).

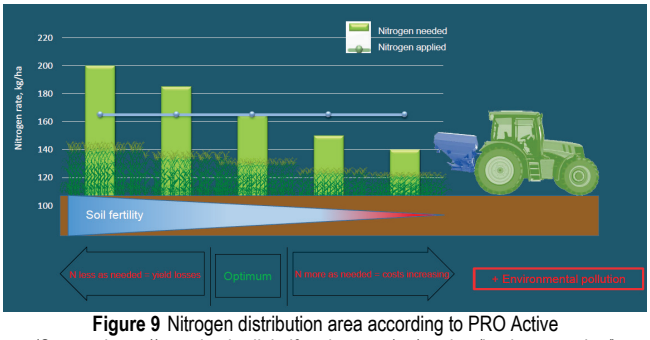


Figure 9 Nitrogen distribution area according to PRO Active
(Source: https://www.isaria-digitalfarming.com/en/product/isaria-pro-active/)

4 CONCLUSIONS

In addition to the navigation system, precision agriculture requires the support of other systems to be completely functional. The most important systems are the system for the application of artificial fertilizers and plant protection. They are equipped with various sensors that read and send data to a processing unit that makes decisions based on the collected data. Technology development has resulted in a wide availability of precision farming. Besides the navigation of aggregates, every bigger farm uses a system of precision agriculture including the growing use of sensors. Nowadays, every new machine comes with a range of various integrated sensors. They convert analogue signals to the digital ones, read and processed through a computer. The data collected by sensors determine further steps of agrotechnical activities with the aim of production improvement. One of the most well- known sensors is *OptRx* with aim to calculate the vegetative indices NDVI and NDRE at the wavelengths of 670, 730, and 760 nm. These sensors can perform in difficult field conditions, unlike other sensor types, which failed to produce accurate data in the same conditions. The advantage of the plant sensor *PRO Active* is the driver's ability to change the settings even in movement, and to adjust the steps of calculations in one work phase. Using application of variabale rate technology (*VRT*) farmers have immediate insight into the condition of the crops and simultaneous application of the product. Farmers must deploy modern agricultural systems to ensure the survival of their production. The large EU market provides ways of easy placement and export of agricultural products of differing quality. The quality as well as the product price can be improved through the application of modern systems and a wise use of resources, which is the goal of the sustainable agricultural production. Future use in precise agriculture is having autonomus robots with sensors for each agrotechnical operation so farmers will be only for monitoring and sending a robot scout as needed.

5 REFERENCES

[1] Chen, H., Chen, L. J., & Albright, T. P. (2007). Predicting the potential distribution of invasive exotic species using GIS and information-theoretic approaches: A case of ragweed (Ambrosia artemisiifolia L.) distribution in China. *Chinese Science Bulletin, 52*(9), 1223-1230. https://doi.org/10.1007/s11434-007-0192-2

[2] Jaganjac, M. (2017). *Influence of seed origin and age on seed viability of weed species Ambrosia artemisiifolia*. University of Zagreb, Faculty of Agriculture. Department of Plant Pathology. (in Croatian)

[3] Lehoczky, É., János, B., & Gellért, G. (2013). Study on the spread, biomass production, and nutrient content of ragweed with high-precision GNSS and GIS device system. *Communications in Soil Science and Plant Analysis, 44*(1-4), 535-545. https://doi.org/10.1080/00103624.2013.744157

[4] Nadih, M., Medverec Knežević, Z., Josipović, R., Grgić, I., & Cvitković, C. (2012). Movement of pollen allergens in the area of Slavonski Brod during pollination seasons 2008-2010. *Archives of Occupational Hygiene and Toxicology, 63*(1), 35-39. https://doi.org/10.2478/10004-1254-62-2011-2117

[5] Rašić, S. (2012). Ambrosia (Ambrosia artemisiifolia L.) - Agronomic and public health problem in the area of Baranja. *Poljoprivreda, 18*(1), 65-66.

[6] https://www.agroklub.com/eko-proizvodnja/ambrozija-korov-alergen-i-lijek/26128/ (Accessed: 24.10.2017)

[7] https://biologija.com.hr/modules/AMS/article.php?storyid=210 (Accessed: 24.10.2017)

[8] Richter, R., Berger, U., Dullinger, S., Essl, F., Leitner, M., Smith, M., & Vogl, G. (2013). Spread of invasive ragweed: climate change, management and how to reduce allergy costs. *Journal of Applied Ecology, 50*(6), 1422-1430. https://doi.org/10.1111/1365-2664.12156

[9] Cvitanović, S., Znaor, Lj., Grbić, D., Gudelj, I., Ivančević, Ž., Zekan Lj., & Perišić, D. (2004). Hypersensitivity to ambrosia elatior pollen in the Split-Dalmatia. *Annual Meeting of the Croatian Society of Allergology and Clinical Immunology of the Croatian Medical Association*, Cavtat.
[10] Ozaslan, C., Onen, H., Farooq, S., Gunal, H., & Akyol, N. (2016). Common ragweed: an emerging threat for sunflower production and human health in Turkey. *Weed Biology and Management, 16*(1), 42-55. https://doi.org/10.1111/wbm.12093
[11] Vuković, I., Mesić, M., Bajić, M., Gold, H., Krtalić, A., Bašić, F., Kisić, I., Zgorelec, Ž., & Sajko, K. (2006). Spatial distribution of soybean weed (Glycine hispida) by ragweed (Ambrosia artemisifolia) in different nitrogen fertilization, based on processing of digital images. *X. Congress of the Croatian Soil Science Society with international participation*, Šibenik, Hrvatska, 14.-17.
[12] Stević, A. (2014). *Application of GIS technology in the system of precision agriculture in the planting of permanent crops*. Josip Juraj Strossmayer University of Osijek, Faculty of Agriculture. (in Croatian)
[13] Jurišić, M. & Plaščak, I. (2009). *GIS geoinformation systems in agriculture and environmental protection*. Faculty of Agriculture in Osijek. (in Croatian)
[14] Andersen, B. J. (2008). Research in the journal Landscape Ecology, 1987–2005. *Landscape Ecology, 23*(2), 129-134. https://doi.org/10.1007/s10980-007-9187-2
[15] Gillespie, T. W., Foody, G. M., & Rocchini, D. (2008). Measuring and modelling biodiversity from space. *Progress in Physical Geography*, 203-221. https://doi.org/10.1177/0309133308093606
[16] Coops, N. C., Wulder, M. A., & Iwanicka, D. (2009). An environmental domain classification of Canada using Earth observation data for biodiversity assessment. *Ecological Informatics, 4*, 8-22. https://doi.org/10.1016/j.ecoinf.2008.09.005
[17] http://geoinformatika.uns.ac.rs/index.php/daljinska-detekcija-i-obrada-slike/ (Accessed: 24.10.2017)
[18] http://www.nrcan.gc.ca/node/9363(Accessed: 24.10.2017)
[19] Cohen, W. B. & Goward, S. N. (2004). Landsat's role in ecological applications of remote sensing. *BioScience, 54*, 535-545. https://doi.org/10.1641/0006-3568(2004)054[0535:LRIEAO]2.0.CO;2
[20] Dezso, B., Fekete, I., Gera, D. A., Giachetta, R., & László, I. (2012). Object-based image analysis in remote sensing applications using various segmentation techniques. In *Annales Universitatis Scientiarum Budapestinensis de Rolando Eotvos Nominatae Sectio Computatorica*, (37), 103-120.
[21] Oštir, K. (2006). *Remote sensing*. Založba ZRC, ZRC SAZU, Ljubljana. (in Slovenian)
[22] Bozja, K. (2010). Visual interpretation of aerial photographs in GE Grosuplje. Biotechnical Faculty, University of Ljubljana, Ljubljana. (in Slovenian)
[23] Kovačić, D. (2019). Sensors and their application in precision agriculture. *Graduate thesis*, Josip Juraj Strossmayer University of Osijek, Faculty of Agrobiotechical Sciences Osijek. (in Croatian)
[24] https://hr.wikipedia.org/wiki/Senzori#cite_note-1 (Accessed: 11.01.2021)
[25] Humo, E. & Kapetanović, M. (1990). *Principles and elements of automatic regulation*, Svjetlost. (in Bosnian)
[26] Povh, F. P., dos Anjos, W. D. P. G., Yasin, M., Harun, S. W., & Arof, H. (2014). Optical sensors applied in agricultural crops. *Optical sensors-New developments and practical applications*, 141-163.
[27] Kadish, A. H. & Hall, D. A. (1965). A new method for the continuous monitoring of blood glucose by measurement of dissolved oxygen. *Clinical chemistry, 11*(9), 869-875. https://doi.org/10.1093/clinchem/11.9.869
[28] Drew, M. C. (1990). Sensing soil oxygen. *Plant, Cell & Environment, 13*(7), 681-693. https://doi.org/10.1111/j.1365-3040.1990.tb01083.x
[29] Smiddy, M., Papkovskaia, N., Papkovsky, D. B., & Kerry, J. P. (2002). Use of oxygen sensors for the non-destructive measurement of the oxygen content in modified atmosphere and vacuum packs of cooked chicken patties; impact of oxygen content on lipid oxidation. *Food Res Int, 35*, 577-584. https://doi.org/10.1016/S0963-9969(01)00160-0
[30] Bogue, R. (2017). Sensors key to advances in precision agriculture. *Sensor Review*. https://doi.org/10.1108/SR-10-2016-0215
[31] Reid, J. F., Zhang, Q., Noguchi, N., & Dickson, M. (2000). Agricultural automatic guidance research in North America. *Computers and electronics in agriculture, 25*(1-2), 155-167. https://doi.org/10.1016/S0168-1699(99)00061-7
[32] Bažon, I. (2009). T*he importance of chemical tests of soil and plant tissue in the cultivation of vines*. University of Zagreb, Faculty of Agriculture in Zagreb. (in Croatian)
[33] Lee, W. S. & Ehsani, R. (2015). Sensing systems for precision agriculture in Florida. *Computers and Electronics in Agriculture*, 112, 2-9. https://doi.org/10.1016/j.compag.2014.11.005
[34] Petrović, D., Jurišić, M., Tadić, V., Plaščak, I., & Barač, Ž. (2018). Different sensor systems for the application of variable rate technology in permanent crops. *Tehnicki glasnik, 12*(3), 188-195. https://doi.org/10.31803/tg-20180213125928
[35] Bradley, B. A. (2014). Remote detection of invasive plants: a review of spectral, textural and phenological approaches. *Biological invasions, 16*(7), 1411-1425. https://doi.org/10.1007/s10530-013-0578-9

Authors' contacts:

Mladen Jurišić, PhD, Full Professor
(Corresponding author)
Faculty of Agrobiotechnical Sciences Osijek,
Vladimira Preloga 1, 31000 Osijek, Croatia
mjurisic@fazos.hr

Ivan Plaščak, PhD, Assistant Professor
Faculty of Agrobiotechnical Sciences Osijek,
Vladimira Preloga 1, 31000 Osijek, Croatia
iplascak@fazos.hr

Željko Barač, PhD, Assistant
Faculty of Agrobiotechnical Sciences Osijek,
Vladimira Preloga 1, 31000 Osijek, Croatia
zbarac@fazos.hr

Dorijan Radočaj, MSc, Assistant
Faculty of Agrobiotechnical Sciences Osijek,
Vladimira Preloga 1, 31000 Osijek, Croatia
dradocaj@fazos.hr

Domagoj Zimmer, PhD, Assistant
Faculty of Agrobiotechnical Sciences Osijek,
Vladimira Preloga 1, 31000 Osijek, Croatia
dzimmer@fazos.hr

ISSN 1846-6168 (Print), ISSN 1848-5588 (Online)
https://doi.org/10.31803/tg-20210219170243

Subject review

Planetary Gearbox Prototype Development and Manufacturing

Jasmin Smajic, Isad Saric, Adil Muminovic, Muamer Delic, Adis J. Muminovic*

Abstract: Goal of this research was to develop and manufacture planetary gearbox prototype using rapid prototyping technology (additive manufacturing). Developed prototype was used to visually analyse the design of the planetary gearbox. Also, it was used to improve and innovate education of students on several courses at Mechanical Design study program at Faculty of Mechanical Engineering. It is shown that low cost rapid prototyping technology can be used to manufacture prototypes of complex machines and machine elements. Prototypes manufactured using this technology have same functionality like the real one. Main limitation is the fact that they cannot sustain real world loads and stresses. This paper shows opportunities which low cost rapid prototyping technology is offering in improvement and innovation of education process at engineering schools and faculties. All complex and heavy machines can be manufactured using this type of technology and on that way more precisely presented to the students.

Keywords: education; mechanical design; planetary gearbox; rapid prototyping

1 INTRODUCTION

When professors at mechanical design courses, like machine elements, wants to present working principles, for some type of machine, they do it on one of the following ways. They can show some drawings and pictures, they can show some videos, or they can go with students to factories or laboratories where those machines can be found. This is possible only if professor has small number of students. He cannot bring one hundred students to the factory just to show them one or two machines and repeat that process for every class. It would be the best if professor can bring some of those machines to the classroom. Unfortunately, this is not possible because, usually, those machines are too heavy. Best examples are gears transmission drives, planetary gearboxes, couplings and brakes. This research is carried out to find out is it possible to use low cost rapid prototyping to manufacture above mentioned machines using lightweight polymer materials. Machines manufactured using this technology will have functionality like the real one and they will be light enough for professors to bring them to the classroom. Planetary gearbox machine is chosen for this research. This area of research is in focus right now because it is important to enable students to feel the parts and assembly in their hands. Research about enhancing the teaching of machine design by creating a basic hands-on environment with mechanical 'breadboards' was done in paper [1]. Similar research can be found in paper [2]. Goal of the research was to improve the mechanical design education introducing hands-on experience with machine parts. Research about development of machine part exhibition and functional mock-ups to enrich design education was carried out in paper [3]. Similar research was done at machine design courses at the United States Air Force Academy and at the University of Texas in Austin in USA in paper [4]. As early mentioned, planetary gearbox is chosen as case study for this research. Today, planetary gearboxes are used in many places where power and torque transmission are needed. Especially in mobile mechanical systems like cars, planes and bouts [5]. Planetary gearboxes are different in comparison to standard gears gearboxes. Main difference is in fact that standard gears gearbox has all shafts loaded in one housing and all shafts are rotating only around their own axes. Planetary gearbox has at least one shaft which is loaded in rotating element. That shaft is rotating around his own axis and around one additional axis [6].

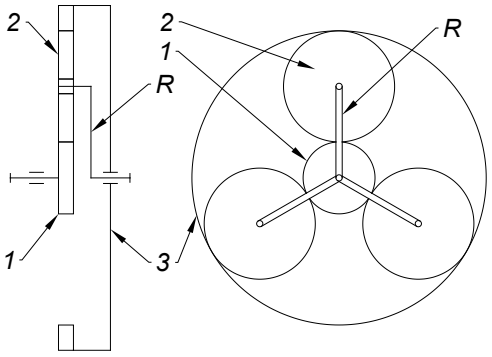


Figure 1 Basic principles of planetary gearbox

Planetary gearboxes remained in focus of research in last few years. Simulation of different types of planetary gearbox was carried out in papers [6-8]. Power loss and efficiency were studied in several research papers and doctoral dissertations. The power loss and efficiency model of a planetary gear transmission system was built with a system modelling method in paper [9]. The method takes number of different transmission elements such as gear, planetary gear sets, hydraulic torque converter, friction disk, lubrication, sealing, bump and motor into consideration and calculates non-load and load power loss for each element. The overall calculated power loss and efficiency are more accurate than the meshing power method. To make simulation more reliable it is compared with the test data [9]. Designing a transmission with goal to maximize efficiency, while keeping operating safety factors in proper boundaries is done in doctoral dissertation [10]. The main purpose of this dissertation was to study the influence of operating conditions and gear oil formulation in the efficiency of meshing gears (applied to a planetary gearbox) including elastic and dynamic effects. Vibrations of planetary

gearboxes are studied in several papers. Planetary gearboxes excite highly modulated vibration. From the existing literature, contradicting descriptions can be obtained. In order to resolve this situation, six commodity gearboxes are investigated on a test rig. A simple, yet powerful method to extract their vibration signatures is proposed in paper [11]. Paper [12] deals with description of a diagnostic device used at the Department of Design and Machine Elements at the University of Zilina which has been built in order to measure, diagnose and evaluate gearbox faults by vibrodiagnostics. Paper [12] describes methods and damage creation process for tested gearboxes. Evaluation of different faults is also processed in paper [12] as well as description of comparative measurements between real and artificially created pitting. Comparison of all measured data with SPM methods is also included.

1.1 Rapid Prototyping

Rapid prototyping technologies are in the focus of research for many authors these days. One of the main manufacturing technology for rapid prototyping is additive manufacturing, especially fused deposition modelling (FDM), which is used in this research for manufacturing of planetary gearbox prototype. Machines for FDM have low cost and they become available for regular people out of the universities and big companies. Detail reviews about rapid prototyping and additive manufacturing can be found in papers [13, 14]. By advancing of additive manufacturing technology, a lot of new questions, challenges and applications emerges. Additive manufacturing technology enables design of machine elements with less mass but in the same time with same stiffness and stress loading capacity. Example of these principals which are used for gears innovative design and manufacturing are shown in paper [15]. Also there are other papers and research about usage of rapid prototyping for gears manufacturing. Main goal of paper [16] was to establish optimal additive manufacturing parameters (printing direction, layer height and percent of infill) which will allow printed gears to replace failed steel gears, for at least some time, enough for spare steel gears to be produced and delivered on site. Special type of polymer material was developed for production of gears using rapid prototyping in paper [17]. Recent developments in additive manufacturing of gears are given in paper [18]. In paper [18] it is stated: "Additive Layer Manufacturing (ALM) is an advanced technology to produce quality gears of metals and plastics. Some significant benefits such as capability to handle complex gear shapes and design, and produce near net-shaped gears; resource efficiency; and rapid product development etc. make this process a sustainable alternate to the other processes of gear manufacturing". From above papers and literature review, it can be seen that rapid prototyping and additive manufacturing can be used for production of planetary gearbox prototype. It is important to notice that dimensional accuracy of gears manufactured using rapid prototyping will be low. Because of this real gear ratio of two gears will significantly differ from analytical one. Example of toothing accuracy was studied in paper [19]. Polymer gears also have several additional problems. Problem of significant deformation during contact of two gears and problem of significant wear of two gears toots in contact. These problems can also affect the gear ratio [20-22]. To solve these problems additional modification of spur gear profile can be carried out [23]. Goal of this paper is to analyse possibilities to use FDM additive manufacturing technology to produce planetary gearbox which can be used for design analysis and for education purposes. Planetary gearbox shown at Fig. 1 is chosen as case study.

2 ANALYTICAL CALCULATION

In this chapter, analytical calculation of planetary gearbox, shown on Fig. 1, is presented. More detail calculation procedure can be found in any book which deals with design of planetary gearboxes, good example is book [24].

Initial data:

$n_1 = 2000$ min^{-1} – rpm of gear 1

$n_3 = -500$ min^{-1} – rpm of gear 3

$i_{13}^{R} = -3$ – gear ratio between gears 1 and 3, in regard to lever R

$P_1 = 25$ kW – power at gear 1

$z_1 = 24$ – number of teeth of gear 1.

2.1 Choosing Number of Satellite Gears and Calculation of Number of Gear Teeth for Gears 2 and 3 of Planetary Gearbox

Equation for gear ratio is given as:

$$i_{13}^{R} = (-1)^k \cdot \frac{z_2 \cdot z_3}{z_1 \cdot z_2} \tag{1}$$

Where is: k – exponent for number of coupling with external gearing; z_2 – number of teeth's of gear 2; z_3 – number of teeth's of gear 3.

From Eq. (1) number of teeth of gear 3 can be calculated as:

$$z_3 = -(-3) \cdot z_1 = 72 \tag{2}$$

Number of teeth of satellite gears 2 can be calculated from the requirement for coaxial characteristic of gears:

$$z_3 = z_1 + 2z_2 \tag{3}$$

From Eq. (3):

$$z_2 = \frac{z_3 - z_1}{2} = 24 \tag{4}$$

Except for requirement for coaxial characteristic of gears, planetary gearboxes which have more satellite gears

must fulfil requirements for neighbourhood satellite gears. They must not come in contact during operation. This requirement must be checked using following equation:

$$\sin\frac{\pi}{4} > \frac{z_2+2}{z_1+z_2} \tag{5}$$

For planetary gearbox shown on Fig. 1, using Eq. (5), following values are calculated and above mentioned requirement is fulfilled:

$$0.707 > 0.54 \tag{6}$$

The third requirement, which has to be fulfilled, is requirement for checking is it possible to carry out proper assembly of satellite gears. If this requirement isn't fulfilled planetary gearbox will have low dynamic characteristics. Assembly of first satellite gear is always possible, but assembly of other two gears won't be possible if this requirement is not fulfilled during design process. This requirement can be checked using following equation:

$$\frac{z_1+z_3}{K} = integer\ number \tag{7}$$

Where is: K = 3 – number of satellite gears, chosen by designer.

For planetary gearbox shown on Fig. 1, using Eq. (7), following values are calculated and above-mentioned requirement is fulfilled:

$$\frac{24+72}{3} = 32 \tag{8}$$

2.2 Calculations of rpm for Gears 2 and 3 and for Lever R of Planetary Gearbox

Analytical calculations of rpm (revolution per minute) for gears inside planetary gearbox are based on calculation of rpm for regular gears (when relative movement to the lever R is observed (lever R is stationary). Gear ratio can be calculated using number of teeth's of that gears, Eq. (9).

$$i_{ab}^{\mathrm{R}} = (-1)^k \cdot \frac{z_b}{z_a} = \frac{n_a - n_{\mathrm{R}}}{n_b - n_{\mathrm{R}}} \tag{9}$$

First, calculation of rpm for lever R needs to be carried out using Eq. (9).

$$i_{13}^{\mathrm{R}} = (-1)^k \cdot \frac{z_3}{z_1} = \frac{n_1 - n_{\mathrm{R}}}{n_3 - n_{\mathrm{R}}} \tag{10}$$

$$n_{\mathrm{R}} = \frac{n_1 - i_{13}^{\mathrm{R}} \cdot n_3}{-i_{13}^{\mathrm{R}} + 1} = 125\ \mathrm{min}^{-1} \tag{11}$$

Now, calculation of rpm for gear 2 for planetary gearbox shown on Fig. 1, using the same Eq. (9) can be carried out.

$$i_{12}^{\mathrm{R}} = (-1)^k \cdot \frac{z_2}{z_1} = \frac{n_1 - n_{\mathrm{R}}}{n_2 - n_{\mathrm{R}}} \tag{12}$$

$$n_2 = \frac{n_1 - n_{\mathrm{R}} + i_{12}^{\mathrm{R}} \cdot n_{\mathrm{R}}}{i_{12}^{\mathrm{R}}} = -1750\ \mathrm{min}^{-1} \tag{13}$$

Where is:

$i_{12}^{\mathrm{R}} = (-1)^k \cdot \frac{z_2}{z_1} = -1$ – gear ratio between gears 1 and 2.

2.3 Design of Gears for Planetary Gearbox

First, initial data needs to be selected. Initial data is same for all gears inside of the planetary gearbox and they are chosen by designer with following values:
m = 2 mm – module
$\beta = 0°$ – helix angle
$\alpha = \alpha_{\mathrm{n}} = 20°$ – pressure angle
ψ = 20 – gear tooth length factor
z_1 = 24 – number of teeth of gear 1.

Diameters and face width of all gears can be calculated according to [25]. Gears 1 and 2 have same dimensions.

Pitch diameter:

$$d_1 = d_2 = m \cdot z_1 = 48\ \mathrm{mm}$$

Addendum diameter:

$$d_{\mathrm{a1}} = d_{\mathrm{a2}} = d_1 + 2m = 52\ \mathrm{mm}$$

Dedendum diameter:

$$d_{\mathrm{f1}} = d_{\mathrm{f2}} = m \cdot (z_1 - 2.4) = 43.2\ \mathrm{mm}$$

Base diameter:

$$d_{\mathrm{b1}} = d_{\mathrm{b2}} = d_1 \cdot \cos\alpha = 45.1\ \mathrm{mm}$$

Face width:

$$b_1 = b_2 = m \cdot \psi = 100\ \mathrm{mm}$$

Gears 1, 2 and 3 are shown on Figs. 2, 3 and 4. Calculation of other machine elements inside planetary gearbox (shafts, bearings, pins etc.) are not presented in this paper because these calculations are too extensive. Those calculations can be found in [24].

Diameters and face width of gear 3 are also calculated.

Pitch diameter:

$$d_3 = m \cdot z_3 = 144\ \mathrm{mm}$$

Addendum diameter:

$$d_{a3} = m \cdot (z_3 - 2) = 140 \text{ mm}$$

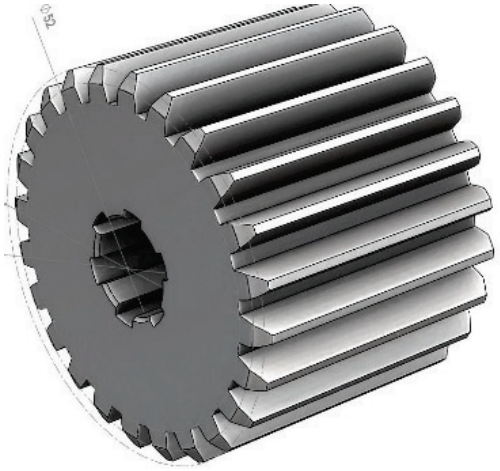


Figure 2 Gear 1

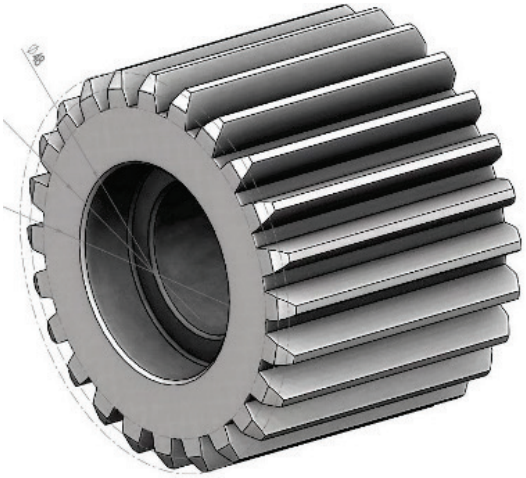


Figure 3 Gear 2

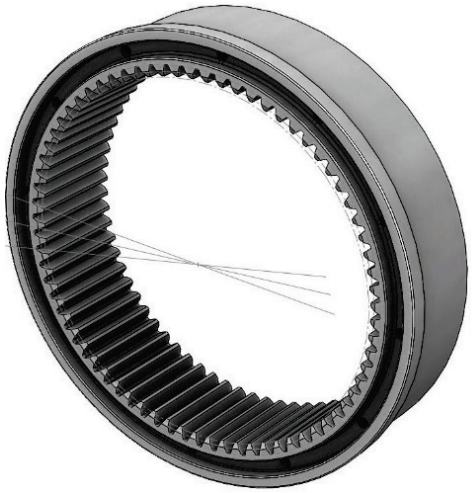


Figure 4 Gear 3

Dedendum diameter:

$$d_{f3} = m \cdot (z_3 + 2.4) = 148.8 \text{ mm}$$

Base diameter:

$$d_{b3} = d_3 \cdot \cos\alpha = 135.32 \text{ mm}$$

Face width:

$$b_3 = m \cdot \psi = 100 \text{ mm}$$

3 DEVELOPMENT OF CAD MODEL AND MANUFACTURING OF PLANETARY GEARBOX

Computer aided design (CAD) model is developed according the calculations which are described in previous chapter. CAD models of gears and shafts are developed according to the calculations. Other machine elements like bearings, screws and pins are chosen as standard elements. CAD model of planetary gearbox housing is developed according to the machine where planetary gearbox will be mounted. Inside gears of developed CAD model of planetary gearbox are shown on Fig. 5.

Figure 5 Inside gears of planetary gearbox

Completely developed CAD model of planetary gearbox is shown on Fig. 6. For manufacturing of planetary gearbox fused deposition modelling (FDM) additive manufacturing technology is selected as most affordable technology for rapid prototyping. For manufacturing, different materials are used for different parts of planetary gearbox. Materials like polylactic acid (PLA), polyethylene terephthalate (PET), co-polyester (CPE), thermoplastic polyurethane (TPU) and polyamide. Manufactured gears are shown on Fig. 7. Gears 1 and 2 are manufactured by combination of two materials, polyamide (gear teeth's) and PET (gear body).

Polyamide is chosen for gears teeth's because it has good wear resistance and good mechanical properties. Basically it lubricates itself, similarly like Politetrafluoretilen (PTFE) material. PET is used for inside parts of gears because it has better mechanical properties than polyamide materials.

Because of those mechanical properties, interference fit can be achieved between real metal bearings and gears. Polyamide and PET have similar thermal properties, which is one of the reasons why those two materials can be used together.

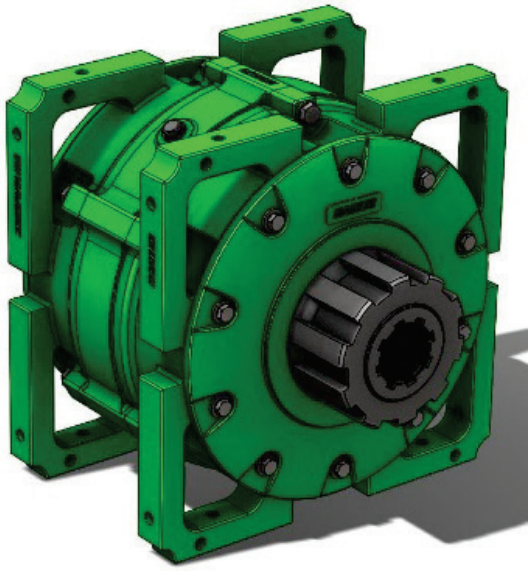


Figure 6 Developed CAD model of planetary gearbox

Gear 3 is manufactured fully from polyamide material. More about different mechanical and thermal properties of materials for additive manufacturing can be found in [26]. Real bearings are used because they are complex machine elements with complex tolerances and fits. They cannot be manufactured using FDM additive manufacturing process if high accuracy is needed, which was the case in the manufacturing process of planetary gearbox. More about tolerances and fits of parts manufactured using additive manufacturing can be found in [27].

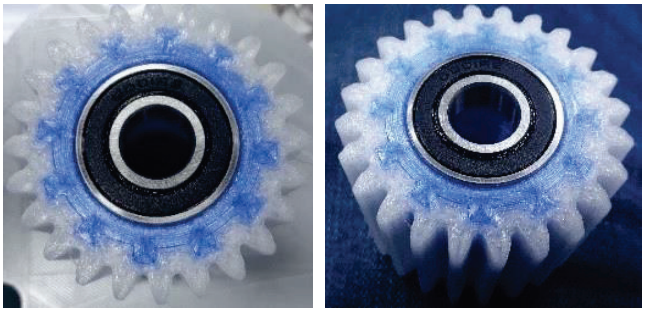


Figure 7 Gears 1 and 2 manufactured by additive manufacturing using two materials

Axles for gears housings are manufactured using CPE+ material because they are the most often loaded parts inside planetary gearbox and CPE+ material has best mechanical properties of all materials available for FDM additive manufacturing up to today (at least to the knowledge of the authors).

Firstly, authors tried to manufacture these axles using PLA material but that axles did not sustain the bending stress loads because stress concentration appear at the places where Seeger rings need to be mounted (Fig. 8).

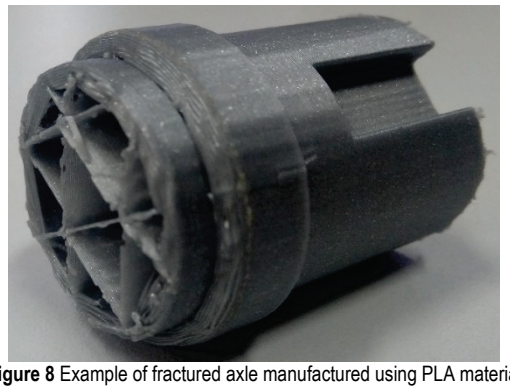


Figure 8 Example of fractured axle manufactured using PLA material

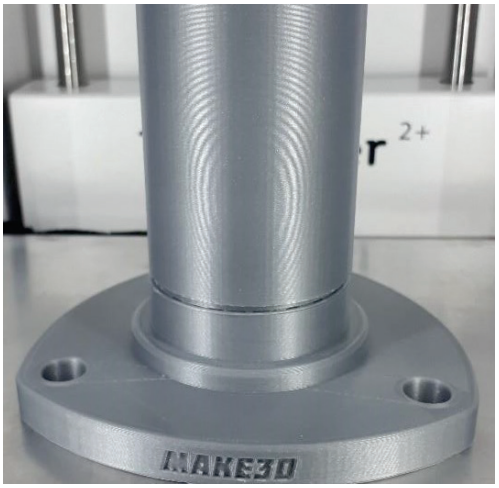


Figure 9 Example of fractured axle manufactured using PLA material

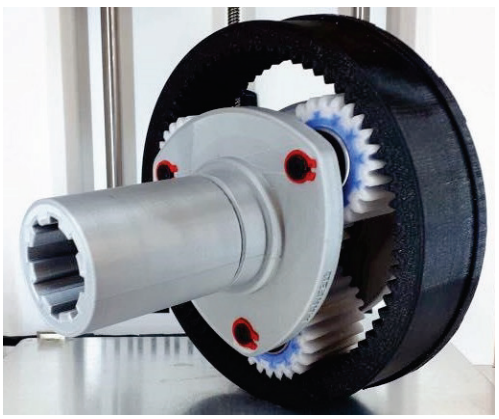


Figure 10 Inside assembly of planetary gearbox

All shafts of planetary gearbox are manufactured using PLA material. Shafts have bigger dimensions and because of that, they can sustain all loads. One of the manufactured shafts are shown at Fig. 9. Seals are manufactured using TPU material. TPU material is additive manufacturing material

which is most similar to rubber materials. Because of that, it can be used as seal.

Housing of planetary gearbox is manufactured using PLA material, because it is most common material with low price and it can fulfil all requirements in this case.

Inside assembly of planetary gearbox are shown on Fig. 10. Full outside assembly are shown on Fig. 11.

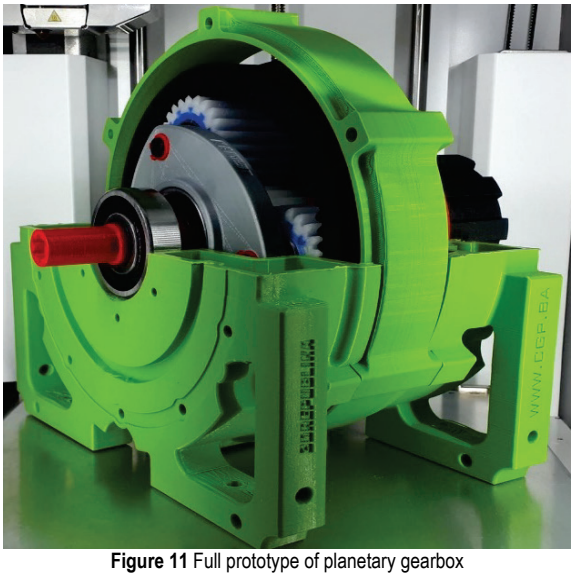


Figure 11 Full prototype of planetary gearbox

4 ANALYSIS OF ROTATION ACCURACY AND IMPROVEMENT OF EDUCATION

After manufacturing of planetary gearbox, analysis of rotation accuracy is carried out. Prototype of planetary gearbox is not intended to be fully loaded because those materials cannot sustain full load like steel. To carry out rotation accuracy analysis, gearbox is loaded with 10% of usually full load, which was enough to measure output rotation speed, calculate measured ratio and compare measured ratio to calculated one by analytical calculation. Results for measured ratio and calculated one are shown in Tab. 1.

Table 1 Table title aligned centre

	Ratio
Analytical calculation	4
Measured on prototype	3.994
Error in %	0.15%

Improvement of education is analyzed thought discussion with the students at several courses at mechanical design study program. All students have positive opinion about this type of improvement of education. It is much easier to explain working principles of machines using fully functional prototype in comparison to videos, pictures or drawings. Future research will focus on design and development of other complex machines using low cost rapid prototyping technology.

5 CONCLUSION

Design, calculation and manufacturing of planetary gearbox is carried out in this paper. Gears and shafts are designed and calculated. Other machine elements (bearings, screws, pins, etc.) are chosen from standard machine elements. Housing of planetary gearbox is also designed. Full planetary gearbox is manufactured using additive manufacturing as the most affordable rapid prototyping technology (except of standard machine elements). FDM additive manufacturing technology is used.

Goal of the research was to find out is it possible to produce prototype of planetary gearbox which will be used to study the design of all elements of planetary gearbox and to use it in educational purpose at mechanical engineering courses. This type of prototype has low weight, so it can be carried out by professor to the classes. It can be fully disassembled and assembled in front of the students. In addition, it has full functionality like the real planetary gearbox. This paper shows opportunities which additive manufacturing is offering in improvement and innovation of education process at engineering schools and faculties. All complex and heavy machines and machine elements can be manufactured using this type of technology and on that way more precisely presented to the students. It can be concluded that planetary gearbox is successfully developed and manufactured.

6 REFERENCES

[1] Wood, J., Campbell, M., Wood, K., & Jensen, D. (2005). Enhancing the teaching of machine design by creating a basic hands-on environment with mechanical 'breadboards'. *International Journal of Mechanical Engineering Education, 33*(1), 1-25. https://doi.org/10.7227/IJMEE.33.1.1

[2] Beckmann, G. & Krause, D. (2010). Improving the mechanical design education by hands-on experience with machine parts. *Proceedings of E&PDE 2010, the 12th International Conference on Engineering and Product Design Education - When Design Education and Design Research meet*, Trondheim Norway, 592-597.

[3] Beckmann, G. & Krause, D. (2011). Machine part exhibition and functional mock-ups to enrich design education. International conference on engineering design. Technical University of Denmark, 130-139.

[4] Wood, J., Jensen, D., & Wood, K. (2005). Enhancing Machine Design Courses through Use of a Multimedia-Based Review of Mechanics of Materials. *Proceedings of the 2005 American Society for Engineering Education Annual Conference & Exposition, American Society for Engineering Education*.

[5] Olegovna Gorshkova, O. & Ivanovich Nekrasov, V. (2018). Planetary gearbox 5R2. *International Journal of Mechanical Engineering and Technology, 9*(11), 1984-1991.

[6] Gajdosik, T., Brumercik, F., Lukac, M., & Drozdziel, P. (2018). Vehicle Planetary Gearbox Simulation LOGI. *Scientific Journal on Transport and Logistics, 9*(1), 11-17. https://doi.org/10.2478/logi-2018-0002

[7] Tianfu, Y. & Shaoze, Y. (2014). Dynamic Simulation of Planetary Gearbox. *Key Engineering Materials*, 584, 220-224. https://doi.org/10.4028/www.scetific.net/KEM.584.220

[8] Ai-Yun, G. & Zhi-Chao, Z. (2018). Transmission Design and Kinematics Simulation of Fixed Gear and Planetary Gear. *IOP Conf. Series: Materials Science and Engineering*, 382. https://doi:10.1088/1757-899X/382/4/042008
[9] Yin, H., Li, S., Zhan, H., Zhao, X., & Zhang, J. (2013). The Power Loss and Efficiency Analysis of a 3DOFs Planetary Gear Box. *Advanced Materials Research*, 345-836, 1285-1289. https://doi.org/10.4028/www.scientific.net/AMR.834-836.1285
[10] Teixeira Margues, P. M. (2017). Power Loss in Planetary Gearboxes Including the Influence of Gear Elastic and Dynamic Effects, *Dissertation*, Departamento de Engenharia Mecânica, Faculdade de Engenharia da Universidade do Porto.
[11] Fritz Ploger, D., Zech, P., & Rinderknecht, S. (2019). Vibration signature analysis of commodity planetary gearboxes. *Mechanical Systems and Signal Processing, 119,* 255-265. https://doi.org/10.1016/j.ymssp.2018.09.014
[12] Kucera, L., Gejdosik, T., & Bucala, J. (2014). The Vibrodiagnostics of Damaged Gears of Planetary Gearboxes. *Comunications,* 16(3), 67-73.
[13] Mahindru, D. V. & Mahendru, P. (2013). Review of Rapid Prototyping-Technology for the Future. *Global Journal of Computer Science and Technology Graphics & Vision, 13*(4), 28-37.
[14] Wong, V. K. & Hernandez, A. (2012). A Review of Additive Manufacturing. *International Scholarly Research Network ISRN Mechanical Engineering*. https://doi.org/10.5402/2012/208760
[15] Muminovic, A.J. Colic, M, Mesic, E., & Saric, I. (2020). Innovative design of spur gear tooth with infill structure. *Bulletin of the polish academy of sciences, technical sciences, 68*(3), 477-483. https://doi.org/10.24425/bpasts.2020.133370
[16] Mitrovic, R., Miskovic, Z., Ristivojevic, M., Dimic, A., Danko, J., Bucha, J., & Rackov, M. (2018). Determination of optimal parameters for rapid prototyping of the involute gears. *IOP Conf. Series: Materials Science and Engineering*, 393. https://doi.org/10.1088/1757-899X/393/1/012105
[17] Oleksy, M., Budzik, G., & Heneczkowski, M. (2010). Hybrid polymer composites for rapid prototyping of gears. *Polimery, 55*(5). https://doi.org/10.14314/polimery.2010.403
[18] Gupta, K. (2018). Recent Developments in Additive Manufacturing of Gears: A Review. *Advanced in Manufacturing Technology.* IOS Press.
[19] Nieszporek, T., Gołębski, R., & Šooš, L. (2017). Analysis of the wormwheel toothing accuracy. *Tehnički vjesnik, 24*(4), 993-1000. https://doi.org/10.17559/TV-20160422094400
[20] Kowalik, M., Rucki, M., Paszta, P., & Gołębski, R. (2016). Plastic Deformations of Measured Object Surface in Contact with Undeformable Surface of Measuring Tool. *Measurement science review* 16(5), 254-259. https://doi.org/10.1515/msr-2016-0031
[21] Gołębski, R. & Szarek, A. (2019). Diagnosis of the Operational Gear Wheel Wear. *Tehnički vjesnik, 26*(3), 658-661. https://doi.org/10.17559/TV-20180321171428
[22] Gnatowski, A., Gołębski, R., & Sikora, P. (2021). Analysis of the Impact of Changes in Thermomechanical Properties of Polymer Materials on the Machining Process of Gears. *Polymers, 13*(1), 13-28. https://doi.org/10.3390/polym13010028
[23] Gołębski, R. and Ivandić, Z. (2018). Analysis of Modification of Spur Gear Profile. *Tehnički vjesnik, 25*(2), 643-648. https://doi.org/10.17559/TV-20171018100732
[24] Zorowski, C. F. (2016). Design of Mechanical Power Transmissions, *Design Engineering Monographs*, Volume 1, CreateSpace Independent Publishing Platform; 1 edition. Scotts Valley, California, SAD.
[25] Budynas, R. G. (2014) *Shigley's Mechanical Engineering Design* McGraw-Hill Education; 10 edition. New York, NY.
[26] Dizon, C. J. R., Espera, Jr, A. H., Chen, Q., & Advincula, R. C. (2018). Mechanical characterization of 3D-printed polymers. *Additive Manufacturing*, 20, 44-67. https://doi.org/10.1016/j.addma.2017.12.002
[27] Lieneke, T., Denzer, V., Adam, G. A. O., & Zimmer, D. (2016). Dimensional tolerances for additive manufacturing: Experimental investigation for Fused Deposition Modeling. *Procedia CIRP*, 43, 286-291. https://doi.org/10.1016/j.procir.2016.02.361

Authors' contacts:

Jasmin Smajic, MSc
University of Sarajevo, Faculty of Mechanical Engineering,
Sarajevo, Bosnia and Herzegovina
Tel.: +387 33 729 800
jasmin@protodevs.com

Isad Saric, Associate Professor
University of Sarajevo, Faculty of Mechanical Engineering,
Vilsonovo šetalište 9, 71000 Sarajevo, Bosnia and Herzegovina
Tel.: +387 33 729 800
saric@mef.unsa.ba

Adil Muminovic, Full Professor
University of Sarajevo, Faculty of Mechanical Engineering,
Vilsonovo šetalište 9, 71000 Sarajevo, Bosnia and Herzegovina
Tel.: +387 33 729 800
muminovic@mef.unsa.ba

Muamer Delic, Senior research assistant
University of Sarajevo, Faculty of Mechanical Engineering,
Vilsonovo šetalište 9, 71000 Sarajevo, Bosnia and Herzegovina
Tel.: +387 33 729 800
delic@mef.unsa.ba

Adis J. Muminovic, Assistant Professor
(Corresponding author)
University of Sarajevo, Faculty of Mechanical Engineering,
Vilsonovo šetalište 9, 71000 Sarajevo, Bosnia and Herzegovina
Tel.: +387 33 729 800
adis.muminovic@mef.unsa.ba

ISSN 1846-6168 (Print), ISSN 1848-5588 (Online)
https://doi.org/10.31803/tg-20210326070107

Subject review

ATLaS: Assistant Software for Life Scientists to Use in Calculations of Buffer Solutions

Ugur Comlekcioglu*, Nazan Comlekcioglu

Abstract: Many solutions such as percentage, molar and buffer solutions are used in all experiments conducted in life science laboratories. Although the preparation of the solutions is not difficult, miscalculations that can be made during intensive laboratory work negatively affect the experimental results. In order for the experiments to work correctly, the solutions must be prepared completely correctly. In this project, a software, ATLaS (Assistant Toolkit for Laboratory Solutions), has been developed to eliminate solution errors arising from calculations. Python programming language was used in the development of ATLaS. Tkinter and Pandas libraries were used in the program. ATLaS contains five main modules (1) Percent Solutions, (2) Molar Solutions, (3) Acid-Base Solutions, (4) Buffer Solutions and (5) Unit Converter. Main modules have sub-functions within themselves. With PyInstaller, the software was converted into a stand-alone executable file. The source code of ATLaS is available at https://github.com/cugur1978/ATLaS.

Keywords: ATLaS; buffer; Pandas; Python; solution; Tkinter

1 INTRODUCTION

There is a high demand for computer-based support for diverse scientific research, but the software that suits the need cannot always be found [1, 2]. While researchers lack the necessary programming skills to develop the required software, software developers are generally unfamiliar with scientific research [3]. Although it is necessary to conduct interdisciplinary studies to solve this problem, it is important to train software developers who are experts in certain scientific fields [4, 5]. Because the cooperation to be achieved by the design, development and distribution of free software by scientists will enable researchers to spend more time on their research [6].

Using programming languages such as C++, Python, Fortran or Pearl, a variety of software, pipelines and packages have been developed to meet all analysis demands of scientific or industrial researchers. Examples of these software include BioCoder[7], Tellurium [8], Biotite [9]. Various web-based tools allow researchers to handle their studies outside of the command-line environment; however, these programs need a stable internet connection and thus hinder offline analysis. Internet-free software with a graphical user interface (GUI) has greatly helped researchers in their work [10].

Python is an interpreted, object-oriented, open-source language, has possibly become the actual standard for investigative, interactive, and computation-driven scientific research [11]. Its ease of learning and use combined with the open-source nature of the language make it an ideal platform for scientific computing [8]. Python help develop computational research tools by providing a balance of clarity and flexibility without decreasing performance [12]. Python stands out with its scientific libraries as well as features such as object oriented and functional programming [13]. Scientific softwares use of a very rich available collection of scientific libraries such as SciPy, NumPy, and Matplotlib. SciPy, for example, has become the de facto standard for leveraging scientific algorithms in Python, with over 600 unique code contributors, thousands of dependent packages, more than 100,000 dependent repositories [14].

In scientific applications, requirements can vary greatly, from basic scripts for usual data analysis with pre-existing toolkits and software to complex general-purpose structures that search to automate and facilitate a wide variety of computational jobs [15]. The place of experimental study in laboratories has always supposed a high profile at all levels of science. However, errors in laboratory experiments can occur in any step of the process. Casadevall et al. [16] reported that more than half of all error-related retractions were attributed to laboratory error. Experimental errors have negative effects in terms of cost, time and effort. In addition, insufficient description of materials and methods limits the reproducibility of the scientific researches [17]. Methods reproducibility mentions to the providing of adequate detail about study protocols and data so the same protocols could, in theory or in actuality, be completely repeated [18]. Protocols need to be highly detailed in order to reduce experimental errors and increase the reproducibility of experiments. However, methods in the literature are usually given without a detailed and complete account of procedures [7].

In this study, we are introducing a stand-alone software ATLaS (Assistant Toolkit for Laboratory Solutions), which is an assistant toolkit that includes basic and widespread calculations of solutions with a user-friendly GUI. This toolkit developed to save time and energy of wet-lab researchers from various calculations of preparing solutions. Additionally, the purpose of this software is to minimize calculation errors in solution preparation in experiments. The code of ATLaS is open, where the software's code could be altered, enhanced or combined in various laboratory softwares. ATLaS is a basic package software that carries out a range of calculations to prepare various solutions for a variety of scientific experiments. Considering that not every laboratory has access to the internet, ATLaS is intended to be software independent from the internet.

2 IMPLEMENTATION

ATLaS is platform-independent software that can be run under all operating systems. The code of the software has

been licensed under MIT and freely available at https://github.com/cugur1978/ATLaS. ATLaS was developed using Python 3.8.5, an interpreted object-oriented high-level programming language that has become broadly adopted in the scientific community due to its clean and open syntax with uncomplicated semantics that make it instinctive to learn, active developer community and free availability [19, 20]. Additionally, Python is very beneficial while building a prototype more quickly with less code. PyCharm 2020.3.2 was used as the coding editor. PyCharm offers a smart code editor and a powerful graphical debugger [21]. Tkinter package is very useful to construct the GUI that contain components such as windows, list boxes, entries etc. Tkinter supplies usability to link codes and functions by pressing buttons and show the output in a variety of options determined by the developer [22].

Modularization is the process of organizing the code into reusable and parametrizable components. Modularization prevents errors, makes code more readable and testable, and simplifies code reuse over redundant duplication [15]. Therefore, ATLaS is designed to consist of 5 main modules. Functions are placed in these modules. A function is a block of code that expresses the solution to a small, independent problem or task. Structuring a program by functions also helps with the modularity and interpretability of the program code and ultimately simplifies the debugging process - an important consideration in all programming projects [19]. The modules used in the calculation of percent and molar solutions contain 3 functions each. These functions perform (1) calculation of percent/molar solutions, (2) dilution and (3) percent/molar conversions. Chemicals in Acid & Base and Buffer Modules are presented to the user as a list. Information such as empirical formula, formula weight of these chemicals are saved in Microsoft Excel files. ATLaS makes calculations by calling these values from the Excel files. Unit Converter module performs concentration conversions under volume, mass and density options. PyInstaller was used to convert ATLaS to a standalone executable software. PyInstaller gathers packages accessed in python software and assemblies locally installed packages in the directory where the application can find the packages in this directory and take the required function from these packages in place of the function in the system. The flow chart used in the design of the software is given in Fig. 1.

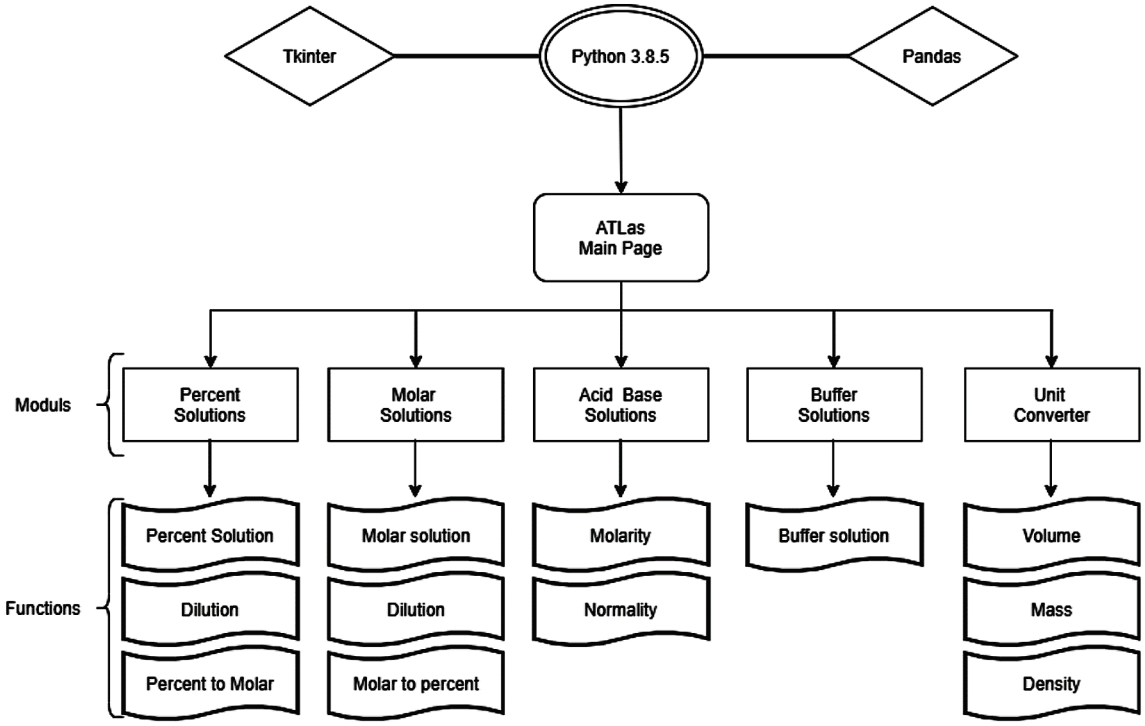


Figure 1 The flowchart used in the development of ATLaS

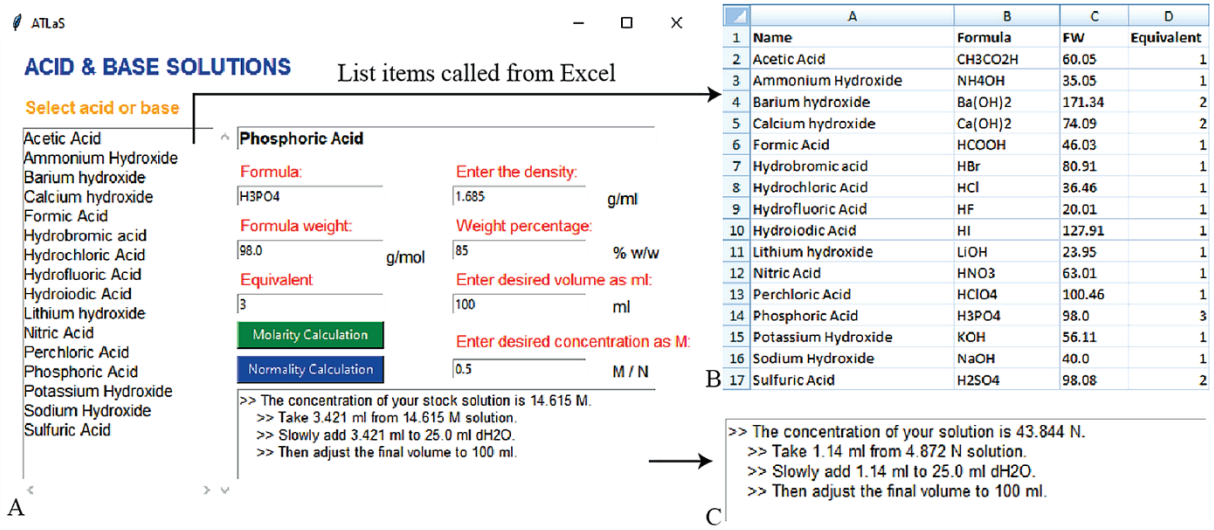
3 RESULTS AND DISCUSSION

The research in life science laboratories requires a diverse collection of software tools. These tools range from laboratory equipment software to data analysis software, and custom software developed to handle the relatively numerous calculations. Researchers increasingly depend on these tools to handle complicated laboratory protocols. Ultimately, research needs in laboratory motivated us to develop an assistant toolkit called ATLaS. The goal of ATLaS is to assist wet-lab scientist with various domains in life science laboratory researches. The benefits it provides at a functional level are unified functions, interface simplicity and efficient usage. Solution calculator is the first domain in ATLaS. We developed a calculator for preparing solutions in experimental studies. In this software, we focused our attention on reducing calculation errors in solution preparation by researchers. Thus, this domain allows researchers to prevent time, labor and financial losses by hindering experimental errors raised from faulty calculations

in solution preparation. Although solution calculations are made on various websites on the Internet, not every site can meet all the calculations needed. For this reason, the researcher may have to navigate various sites to make the calculation he/she wants. In addition, the lab may not have stable internet access or internet connection speeds may be low. ATLaS collects the calculations that may be needed while preparing solutions by life scientists in a single software. It does not require internet connection with its stands-alone structure. The versatility of a program comes from the variety of functions it has. ATLaS includes 10 functions under 5 modules. Since the documentation will become more important in software development, modules and the overall functions of ATLaS were illustrated in the user manual and available at https://github.com/cugur1978/ATLaS/blob/main/ATLaS_User_Manuel.pdf

The modular development of ATLaS provided an advantage in debugging. The modules written separately were brought together after the errors were corrected. In this way, the codes can be read more easily for those who want to develop ATLaS by cloning. A good GUI makes an application intuitive and easy to use. Tkinter, which is default graphical user interface widget set for Python, was used for GUI. Tkinter was selected because of its availability on all operating systems [23]. Graphical user interfaces allow the user to send information into the program without accessing the code [24]. One of our main purposes was that the GUI of ATLaS had a simple interface. It can be confusing to present all parameters in a single interface, so ATLaS is designed modularly. Thus, even the first person to use the program can make calculations without difficulty.

Scientific software developed by researchers typically appeals to a very narrow audience [25]. Effective scientific software should be coded to meet the needs of the researcher over a long period. Scientific software may produce the intended results in developers hands, however, the potential new user may not benefit in a similar manner. In order to enable ATLaS be flexible enough to adapt to a variety of laboratories, chemical information did not inserted into the codes. Taking into account the difference of the solutions or chemicals needed in different laboratories, ATLaS allows the researcher to create a chemical database in Acid-Base and Buffer solution modules. The information in these modules is called from the Microsoft Excel file located in the same folder as ATLaS. Python language uses the Pandas library for processing spreadsheet-format data such as Excel and therefore to read the data in Excel files, Pandas library was imported to ATLaS. If the researcher enters the information of the chemicals required, depending on the format in the Excel file, ATLaS will use this information in calculations. Finally, calculation results are reported to the user as a recipe. Thus, the results were made more understandable especially for students and young researchers who start working in research laboratories.



	A	B	C	D
1	Name	Formula	FW	Equivalent
2	Acetic Acid	CH3CO2H	60.05	1
3	Ammonium Hydroxide	NH4OH	35.05	1
4	Barium hydroxide	Ba(OH)2	171.34	2
5	Calcium hydroxide	Ca(OH)2	74.09	2
6	Formic Acid	HCOOH	46.03	1
7	Hydrobromic acid	HBr	80.91	1
8	Hydrochloric Acid	HCl	36.46	1
9	Hydrofluoric Acid	HF	20.01	1
10	Hydroiodic Acid	HI	127.91	1
11	Lithium hydroxide	LiOH	23.95	1
12	Nitric Acid	HNO3	63.01	1
13	Perchloric Acid	HClO4	100.46	1
14	Phosphoric Acid	H3PO4	98.0	3
15	Potassium Hydroxide	KOH	56.11	1
16	Sodium Hydroxide	NaOH	40.0	1
17	Sulfuric Acid	H2SO4	98.08	2

Figure 2 Acid and base solution module (A), Excel file called from ATLaS (B) and Normal Calculation output (C)

As an example, the calculations required for preparing 0.5 M and 0.5 N phosphoric acid solutions are shown in the application in Fig. 2. Acid and Base Solution module in ATLaS contains 16 acids and bases. The formulas, formula weights and equivalent values of these chemicals are called from the Excel file. The researcher could add more acid and bases to this Excel file, thus the chemical database could be expanded by the user. However, density and weight percentage values are requested from the user. This is because these values may differ according to the brands of chemicals used in laboratories. As seen in Fig. 2, when phosphoric acid is selected from the list and the relevant fields are filled, the outputs can be seen when the molarity or normality buttons are pressed. Instead of giving the calculated values directly to the user, the preparation of the solution comes as a recipe as more understandable laboratory instructions. For this, the calculated values are assigned to the defined variables and placed in the codes containing instructions.

The open-source code of ATLaS enables the developers to be able to better understand the methodology and reproduce the results. Open-source software development has had remarkable effect on scientific research. Open sharing not only enables the scientific approach through

replication, validation, and error checking, sharing is the key to a sustainable forthcoming for computational research, and publishers require open-source code for reviewing the software used to generate results [26]. However, the retainability of softwares after publication is presumably the most important problem faced by scientists who develop it [27]. Additionally, version control is necessary for sustainable software development [25]. In order to overcome these issues, ATLaS uploaded to GitHub, which is a popular web-based hosting service for Git version control. GitHub provides a useful software development platform, wherein developers can upload their open-source projects. The most important issue in a repository is having a license that clearly defines the permissions and restrictions attached to the code and other files in the repository [28]. Since ATLaS was deposited in GitHub under the license of MIT, which gives permissions without limitation to use copy and modify, it is possible for other developers to develop this software.

4 CONCLUSIONS

We took into account "Release early, release often" as an open-source mantra, and reported the first version of ATLaS in this study. We aim to present new versions to researchers by adding different modules to ATLaS. Scientific software development is a significant need that has to be fulfilled. It is essential that experiments be analyzed in a reproducible manner. Computational research software systems allow for the standardization of analysis pipelines, thus enables the scientific studies repeatable in different laboratories.As scientists, we need assistant softwares that will standardize laboratory protocols and calculations. Development of open-source software is a collective process and therefore our expectation is that different scientists and software developers will be involved in the development of ATLaS.

5 REFERENCES

[1] Kohl, M., Wiese, S., & Warscheid, B. (2011). Cytoscape: software for visualization and analysis of biological networks. In: Hamacher M., Eisenacher M., Stephan C. (eds) *Data Mining in Proteomics. Methods in Molecular Biology (Methods and Protocols), vol 696*. Humana Press. https://doi.org/10.1007/978-1-60761-987-1_18

[2] List, M., Ebert, P., & Albrecht, F. **(**2017**)**. Ten simple rules for developing usable software in computational biology. *PLoS Computational Biolology, 13*(1), e1005265. https://doi.org/10.1371/journal.pcbi.1005265

[3] Wang, A., Yan, X., & Wei Z. (2018). ImagePy: an open-source, Python-based and platform-independent software package for bioimage analysis. *Bioinformatics, 34*(18), 3238-3240. https://doi.org/10.1093/bioinformatics/bty313

[4] Deardorff, A. (2020). Why do biomedical researchers learn to program? An exploratory investigation. *Journal of the Medical Library Association, 108*(1), 29. https://doi.org/10.5195%2Fjmla.2020.819

[5] Dagdia, Z. C., Avdeyev, P., & Bayzid, M. S. (2021). Biological computation and computational biology: survey, challenges, and discussion. *Artificial Intelligence Review*, 1-67. https://doi.org/10.1007/s10462-020-09951-1

[6] Morin, A., Urban, J., & Sliz, P. (2012). A quick guide to software licensing for the scientist-programmer. *PLoS Computational Biology, 8*(7), e1002598. https://doi.org/10.1371/journal.pcbi.1002598

[7] Ananthanarayanan, V. & Thies, W. (2010). Biocoder: A programming language for standardizing and automating biology protocols. *Journal of Biological Engineering, 4*(1), 1-13. https://doi.org/10.1186/1754-1611-4-13

[8] Choi, K., Medley, J. K., König, M., Stocking, K., Smith, L., Gu, S., & Sauro, H. M. (2018). Tellurium: an extensible python-based modeling environment for systems and synthetic biology. *Biosystems*, 171, 74-79. https://doi.org/10.1016/j.biosystems.2018.07.006

[9] Kunzmann, P. & Hamacher, K. (2018). Biotite: a unifying open source computational biology framework in Python. *BMC Bioinformatics, 19*(1), 1-8. https://doi.org/10.1186/s12859-018-2367-z

[10] Chen, C., Chen, H., Zhang, Y., Thomas, H. R., Frank, M. H., He, Y., & Xia, R. (2020). TBtools: an integrative toolkit developed for interactive analyses of big biological data. *Molecular Plant, 13*(8), 1194-1202. https://doi.org/10.1016/j.molp.2020.06.009

[11] Millman, K. J. & Aivazis, M. (2011). Python for scientists and engineers. *Computing in Science & Engineering, 13*(2), 9-12. https://doi.org/10.1109/MCSE.2011.36

[12] Perez, F., Granger, B. E., & Hunter, J.D. (2010). Python: an ecosystem for scientific computing. *Computing in Science & Engineering, 13*(2), 13-21. https://doi.org/10.1109/MCSE.2010.119

[13] Rashed, M. G. & Ahsan, R. (2012). Python in computational science: applications and possibilities. *International Journal of Computer Applications, 46*(20), 26-30. https://doi.org/10.5120/7058-9799

[14] Virtanen, P., Gommers, R., Oliphant, T. E., Haberland, M., Reddy, T., Cournapeau, D., Burovski, E., Peterson, P., Weckesser, W., & Bright, J. (2020). SciPy 1.0: fundamental algorithms for scientific computing in Python. *Nature Methods, 17*(3), 261-272. https://doi.org/10.1038/s41592-019-0686-2

[15] Balaban, G., Grytten, I., Rand, K. D., Scheffer, L., & Sandve, G. K. (2021). Ten simple rules for quick and dirty scientific programming. *PLOS Computational Biology, 17*(3), e1008549. https://doi.org/10.1371/journal.pcbi.1008549

[16] Casadevall, A., Steen, R. G., & Fang, F. C. (2014). Sources of error in the retracted scientific literature. *The FASEB Journal, 28*(9), 3847-3855. https://doi.org/10.1096/fj.14-256735

[17] Prinz, F., Schlange, T., & Asadullah, K. (2011). Believe it or not: how much can we rely on published data on potential drug targets? *Nature reviews Drug Discovery, 10*(9), 712-712. https://doi.org/10.1038/nrd3439-c1

[18] Goodman, S. N., Fanelli, D. & Ioannidis, J. P. (2016). What does research reproducibility mean? *Science Translational Medicine, 8*(341), 341ps12-341ps12. https://doi.org/10.1126/scitranslmed.aaf5027

[19] Ekmekci, B., McAnany, C. E., & Mura, C. (2016). An introduction to programming for bioscientists: a Python-based primer. *PLoS Computational Biology, 12*(6), e1004867. https://doi.org/10.1371/journal.pcbi.1004867

[20] Fourment, M. & Gillings, M. R. (2008). A comparison of common programming languages used in bioinformatics. *BMC Bioinformatics, 9*(1), 1-9. https://doi.org/10.1186/1471-2105-9-82

[21] Jeon, J. & Kim, H. U. (2020). Setup of a scientific computing environment for computational biology: Simulation of a

genome-scale metabolic model of *Escherichia coli* as an example. *Journal of Microbiology, 58*(3), 227-234. https://doi.org/10.1007/s12275-020-9516-6

[22] Habib, P. T., Alsamman, A. M., & Hamwieh, A. (2019). BioAnalyzer: Bioinformatic software of routinely used tools for analysis of genomic data. *Advances in Bioscience and Biotechnology, 10*(03), 33. https://doi.org/10.4236/abb.2019.103003

[23] Vlachoudis, V. (2009). FLAIR: a powerful but user friendly graphical interface for FLUKA. *Proceedings of International Conference on Mathematics, Computational Methods & Reactor Physics,* Saratoga Springs, New York.

[24] Moruzzi, G. (2020). Essential Python for the Physicist, Springer International Publishing. https://doi.org/10.1007/978-3-030-45027-4

[25] Taschuk, M. & Wilson, G. (2017). Ten simple rules for making research software more robust. *PLOS Computational Biology, 13*(4), e1005412. https://doi.org/10.1371/journal.pcbi.1005412

[26] Osborne, J. M., Bernabeu, M. O., Bruna, M., Calderhead, B., Cooper, J., Dalchau, N., Dunn, S.-J., Fletcher, A. G., Freeman, R., Groen, D., Knapp, B., McInerny, G. J., Mirams, G. R., Pitt-Francis, J., Sengupta, B., Wright, D. W., Yates, C. A., Gavaghan, D. J., Emmott, S., & Deane, C. (2014). Ten simple rules for effective computational research. *PLOS Computational Biology, 10*(3), e1003506. https://doi.org/10.1371/journal.pcbi.1003506

[27] Prlić, A. & Procter, J. B. (2012). Ten simple rules for the open development of scientific software. *PLOS Computational Biology, 8*(12), e1002802. https://doi.org/10.1371/journal.pcbi.1002802

[28] Perez-Riverol, Y., Gatto, L., Wang, R., Sachsenberg, T., Uszkoreit, J., Leprevost, F. D. V., Fufezan, C., Ternent, T., Eglen, S. J., & Katz, D. S. (2016).Ten simple rules for taking advantage of Git and GitHub. *PLOS Computational Biology, 12*(7), e1004947. https://doi.org/10.1371/journal.pcbi.1004947

Authors' contacts:

Ugur Comlekcioglu
(Corresponding author)
Kahramanmaras Sutcu Imam University,
Biotechnology Laboratory,
46050, Kahramanmaras, Turkey
E-mail: cugur1978@gmail.com

Nazan Comlekcioglu
Kahramanmaras Sutcu Imam University,
Biology Department,
46050, Kahramanmaras, Turkey

ISSN 1846-6168 (Print), ISSN 1848-5588 (Online)
https://doi.org/10.31803/tg-20210416103500

Subject review

An Overview of Precision Irrigation Systems Used in Agriculture

Ivan Plaščak, Mladen Jurišić, Dorijan Radočaj, Milan Vujić, Domagoj Zimmer*

Abstract: The introduction of precision agriculture increased the efficiency of plant production, while simultaneously reducing the production cost. Precision irrigation can be considered as the combination of sensors, computer software and irrigation systems. Precision irrigation has reduced water consumption and increased yields, and thus increased economic profits. The development of new crop monitoring technologies in precision irrigation has been made possible by the imaging and analysis of real-time crop condition data. The aim of this study was to describe the present state and possibilities of precision irrigation in practice in the EU and Croatia. An overview of the current precision irrigation technologies, as well as its adaptive management to the decision-making in agricultural water management, represents a fundamental basis for future practical studies in precision irrigation.

Keywords: micro-irrigation/flooding; precision agriculture; rainfall irrigation/flooding; sensors; simulation; surface irrigation/flooding

1 INTRODUCTION

The application of irrigation systems in agriculture in Europe is near 30%, while in Croatia it is only about 2% [1]. The available water levels are in constant decline in the world, which urges for the accurate determination of the exact amount of water required by the crops during the growing season. Precision agriculture is defined as the technology based on the identification and management of variabilities within the agricultural field for optimal profitability, sustainability and protection of land resources [2]. The advantages of precision agriculture in terms of economic and environmental benefits are in the reduced use of water, fertilizers, herbicides and pesticides [3]. One of the most important areas in which precision agriculture is applied is the management of soil properties heterogeneity, which is crucial for most agrotechnical operations [4]. Precision irrigation requires the possession of soil-related information such as: texture, water capacity, moisture and crop water demand at certain growth stages. The procedures within precision irrigation are supported by technical components, such as sensors and computer processing software.

In the water the soil is bound to the soil particles with the force that the root system must overcome during the water absorption. Therefore, water in the soil is divided into accessible (free) and inaccessible (bound). The forces that hold water along the soil particles are the moisture tension (surface, hydrostatic and gravitational forces), and the osmotic pressure of the water soil phase [5]. In [6], on agricultural lands that do not have enough water for crop production during their partial or full growth period, water should be artificially applied. All operations which include the man-made and artificial increase of the soil water content with the aim of crop production are considered as irrigation.

Author [7] stated that thermal remote sensing used for the determination of crop water content is based on the emitted radiation of the plant in relation to the temperature difference between the leaf and stem. It significantly varies with air temperature and evapotranspiration intensity. The best method for determining soil moisture in potato cultivation were studied in research of [8]. The authors noted the efficiency of watermark tensiometers for that application. However, they emphasize the need for a calibration curve in order to relate the values of pressure (kPa or cbar) and volume of soil water content (vol%) to the current soil moisture. The same authors stated that Aquaterr sensors were sensitive to changes in soil temperature and therefore do not recommend their use in potato cultivation. According to [9], the efficiency of watermark sensors depends on weather conditions. The depth of sensor placement should not be the same in average climatic years and in years with extreme weather conditions. Authors [10] measured soil water content on five soil types with the help of electrical conductivity, and the influence of the change in the amount of water for future soil mapping was confirmed, similar to measures of [11]. Many authors [5, 12] divided the irrigation systems into three fundamental methods: surface irrigation/flooding, rainfall irrigation/flooding and micro-irrigation systems.

2 THE DEVELOPMENT OF PRECISION IRRIGATION

Research related to precision irrigation began in the United States in the early 1990s. The research was largely based on the modification of mobile irrigation systems that are able to cover a large area and apply a diverse amount of water. Such systems were controlled using the input spatial data [13]. Various procedures have been evaluated to implement valve control to achieve the desired application of irrigation rates. It was concluded that due to the cost and complexity of these systems, economic feasibility depends on large agricultural production and does not pay off for small farmers [14]. The number of studies by European researchers regarding precision irrigation increased in the 2000s and emphasis was placed on the purpose and performance of spatially variable irrigation rates [15-19].

The studies conducted by [20] and [21] included the application of an infrared thermometer mounted on a rain wing. These pivot systems were used for the data collection of soil temperature and plant surface temperature for the development of automatic irrigation. Authors [20] concluded that the method of modeling the dynamics of crop cover temperature can be cost-efficient. Due to the low cost and simplicity of the method, this method became accessible for smaller farmers as well.

Additional research conducted in Europe, according to authors [15], focused on variations in yields due to uneven irrigation. In New Zealand, authors [22] investigated water savings and the economic benefits of precision irrigation using pivot systems. Common features of these studies include: the emphasis on system design and control to obtain spatially diverse applications; the use of global navigation satellite system (GNSS) for irrigation control using previously created soil maps; and differential irrigation in the areas from 40 to 100 m^2. Authors [16] focused on the development and testing of digital control systems that use an embedded computer to process and apply transmitted radio waves. They used the low-energy precision application (LEPA) system on the pivot irrigation system. It was concluded that pivot systems and LEPA can be corrected for the application of spatially different irrigation. The common precision irrigation strategy was to change the amount of water rates, and thus the depth of water application. Precision irrigation relies on the development of the appropriate irrigation management systems based on the data collected about the crop requirements for water and nutrients in real-time.

The notion of spatially variable irrigation is based on the hypothesis that each plant requires a non-uniform amount of water due to the difference in root system depth. The yield is maximum if each plant receives the exact amount of water it requires, considering the within-field heterogeneity [16].

The primary objective of precision irrigation is to optimize the amount of water in the entire agricultural field. Variable-rate irrigation in specific locations can achieve significant water savings [14]. According to authors [19], variable-rate can produce water savings in the range from 10 to 15 % compared to the conventional methods. Authors [23] even estimated that the potential water savings using precision irrigation can reach about 25 %.

Authors [24] observed that the potato yield using the pivot systems based on the spatially variable irrigation systems can increase the yield from 4 to 6 %. Crop modeling and spatially variable irrigation have proven to be essential and effective means of yield management. Two authors [25] used the CERES model to model maize crops and the feasibility of maize irrigation. Spatially variable irrigation also resulted in higher maize yields. However, in some instances, multiple authors [26-28] pointed to the fact that such a system might not be profitable for small farmers.

3 PRECISION IRRIGATION METHODS AND SYSTEMS

3.1 Surface/flooding Irrigation

The rirmod irrigation model has been accepted as a standard for the evaluation and optimization of surface furrow irrigation in Australia [29]. It is based on solving full hydrodynamic equations and its accuracy is determined only by input parameters. This model uses real-time irrigation data and creates irrigation statistics for future use. Using the Winsrfr model and the aim model, many authors [30, 31] used approximate hydrodynamic equations and their accuracy was determined only for individual situations.

Real-time automation and adaptability control produced quality results for managing infiltration time variability. According to authors [32], this procedure ensures greater efficiency of irrigation compared to traditional irrigation estimates, allowing significant labor savings. The real-time control system monitors the water movement along the furrow. It determines the characteristics of soil absorption through the simulation procedure and therefore modifies the input variables (water flow and moment of irrigation cessation). If the set irrigation parameters are continuous and change automatically, it means that the irrigation system is adaptable to the conditions in the field.

AWMA Pyt Ltd, is an Australian company that developed the aquator system for automatic and remote control of water resources. Operations assigned via aquator are transmitted by a device that is most commonly mounted on the base station roof. The control openings have built-in receivers and are powered via solar panels. Reverse remote reading was developed by authors [33] as an alternative contact sensor that serves to monitor the progress of water entry into the furrows and allow automatic control of water flow. The camera is located at the field boundary and images water flowing down the furrow during irrigation. The images are analyzed by a computer system to calculate the actual position of the incoming water.

Authors [32] laid the foundations for the practical control of furrow irrigation in real-time. The proposed system includes: automatic start of inflow into furrows and its measurement; measuring the water flow through the furrows; real-time assessment of soil infiltration and soil moisture deficiency; real-time simulation and optimization of interruption time and automatic shutdown of inflow at the set time. The system performs all procedures without user interaction.

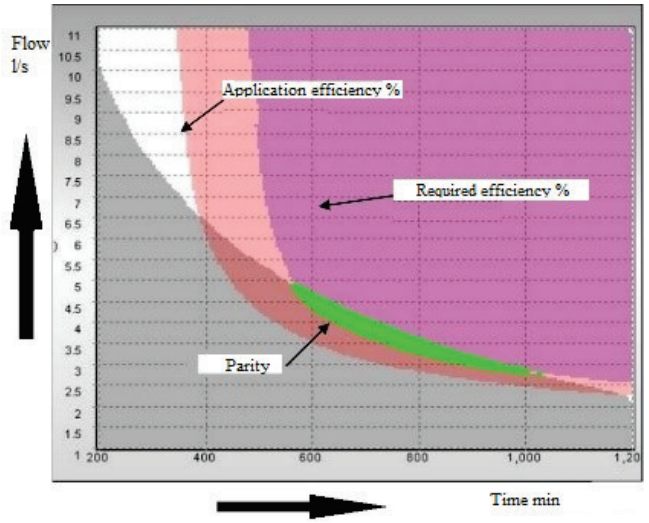


Figure 1 IrriPro optimization screen [34]

Decision-making software is an important segment for such a system and includes: continuous flow measurement using pressure measurement in the supply system; earlier soil characterization by determining the soil type; and the probability of water infiltration into the soil. The IrriPro software package was developed to extend the hydraulic modeling of a single furrow or an entire field. It uses

hydrodynamic equations and multiple simulations for each furrow in the field and combines the results to create 2D networks of applied depths (Fig. 1 and 2). It then determines the flow rate and the end time of the flow in order to achieve maximum effect.

Fig. 1. represents an example of the IrriPro optimization screen, which lists the parameters for multiple furrows in the entire field. The green area indicates the zone of optimal performance. Fig. 2 shows the predicted irrigation end periods for 84 furrows, considering the heterogeneity of the furrows.

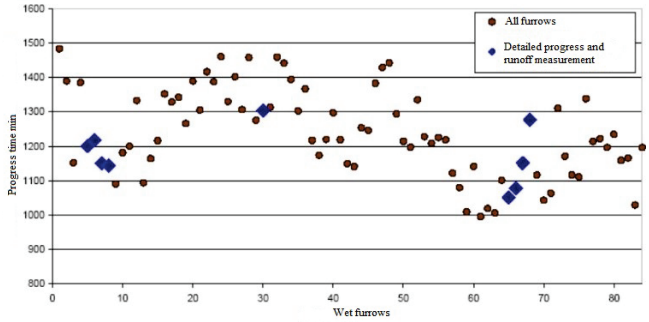


Figure 2 IrriPro predicted irrigation end periods [34]

3.2 Rainfall Irrigation

Simulations of rainfall irrigation/flooding models have been rapidly evolving over the last two decades. The computer software Space Pro includes the known templates for the purpose of selecting the size and spacing of the sprayers for the maximization of irrigation uniformity. This software relies on known parameters for each sprayer, such as the pressure and above ground height. The wind influence is usually neglected in the process, which impairs the efficiency of the sprayer [35]. Two main approaches are commonly used: a ballistic approach to calculate the flight path of individual water droplets; and an empirical approach involving extrapolation from measured parameters. These parameters include varying wind speeds and directions, pressure and droplet flight path.

Travgun is the model developed by authors [36], which uses the irrigation direction to calculate the wind-free pattern and to determine the six parameters used to adjust the wind impact pattern. The information obtained from the model is an estimate of the uniformity of irrigation application for any angle, distance, droplet flight path, wind speed and direction. The model does not predict irrigation depths at specific points in the field. The purpose of all models is to assess the uniformity of irrigation, the selection of appropriate nozzles and their spacing.

Of all irrigation systems, rainwater irrigation systems offer the greatest potential for uniform irrigation, as they are easily adaptable for spatially variable management. Significant progress has been made in the development of hardware to control the pivot system with the aim of achieving irrigation precision. According to authors [37], further development of decision-making tools in irrigation pivot systems is needed to achieve optimal irrigation accuracy.

A number of technologies for the variable water irrigation have been developed, classifying them as [16]: multiple discrete devices combined with a constant application rate to achieve irrigation depth; a fixed flow rate device with the possibility of rapid interruption to ensure a range of depth of irrigation application; and variable sprayers with time control. A control system has also been developed to control the irrigation speed for each individual sprayer. Key criteria in the development of these technologies include: ease of installation in existing commercial irrigation systems; adequate uniformity of water application within the management zone; compatibility with existing irrigation system equipment; reduction of robust electronics; two-way communication; and the possibility of future upgrade.

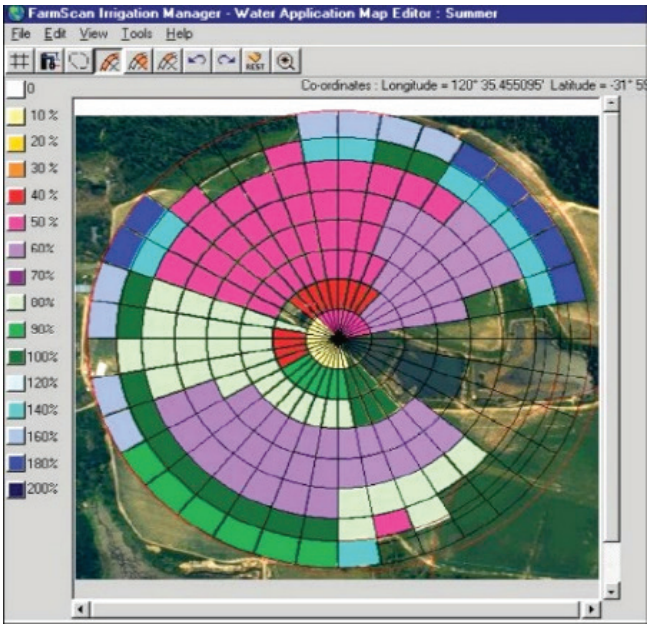


Figure 3 Farmscan irrigation rates [34]

To achieve higher precision of water application to a specific location, the exact locations of all elements for irrigation application must be known. To determine the center pivot locations, either multiple electronic compasses that continuously measure inconsistencies along the length of the system; or GNSS for positioning at one or more locations are used. The pivot devices for application with variable irrigation rates are currently commercially available technology. The farmscan 7000VRI is a system used to control the center pivot device [34]. The prescribed maps were created using a personal computer (Fig. 3). The application map separates the circular areas covered by the sprayer into circular clips with an angle of 2° to 10° and each clip is divided into segments. Irrigation installments per segment are variable values and it is possible to mark several or all segments for irrigation. The irrigation rates calculated in this way can easily be transferred to the controller. If irrigation rates are to be increased above 100 %, the sprayer will automatically slow down.

Farmscan system supports the creation of five irrigation rates. Up to 48 zones can be irrigated by adding auxiliary nozzles located along with the supports. The nozzles are grouped into blocks, and the blocks are controlled by the main line that is electronically controlled by a controller [34]. Farmscan irrigation management map divides the agricultural area into cells that are differently colored according to the percentage of water available to the crops. Since soils have different structures, varying water retention capacities and infiltration rations, irrigation rates may differ between different zones in one agricultural field [34]. Sensor systems can be more accurate than those based on maps due to access or data collection in real-time. Control systems that dynamically collect data using remote sensing or built-in sensors on the irrigation system are under development [38].

Automated irrigation control systems use sensors grouped in one location. This management method uses only the obtained soil properties data for irrigation planning and aims at crop uniformity in the field, without optimizing production in different parts of the field. However, the local microclimate, plant genetics and the occurrence of infestation/pests in crops can result in one area having a different yield compared to another. The system developed by authors [39] creates a soil map based on data obtained from neutron probes which provide soil moisture data and meteorological stations.

Most conventional irrigation systems are designed to operate with a constant flow in the system and pressure on the sprinklers. In precision irrigation, pivot irrigation systems use constant pressure but variable water flow. Possible solutions for variable water supply are multi-pump systems or the use of a variable speed pump [16].

3.3 Micro-Irrigation Systems

Micro-irrigation systems are designed for the exclusive irrigation of the zone in the plant proximity. The advantages of this approach are: irrigation of a smaller area, minimal water evaporation from the soil surface, reduced weed presence, and uniform water application in the root zone of the plant. A special advantage of micro-irrigation is the addition of a smaller amount of water at short irrigation intervals. This provides the ability to maintain soil moisture with a certain water deficit below the capacity of the field. It can be managed throughout the entire season or only its part, thus achieving greater irrigation efficiency and reducing irrigation costs. The efficiency of micro-irrigation can be higher than 90 % [40].

Water losses in micro-irrigation mainly occur by evaporation of water from the soil surface and outflow of water into the drainage. Evaporation losses are small due to the limited irrigation area and no standing water on the soil surface. The causes of possibly uneven irrigation in micro-systems are the length of the pipe, pressure oscillations and clogging of the applicator during its operation. The micro-irrigation system has a higher potential for widespread implementation compared to other systems. Management is easy and is usually automated based on time, soil moisture, or surrounding temperature [40].

Authors [41] used a system for monitoring the moisture in the root zone in viticulture and measured soil moisture in a closed-loop system. Authors [42] focused on the development of a spatially variable micro-irrigation system that enables the management of individual micro applicators (droppers) in an orchard. The basis of the research was a varying water supply for one or more individual trees located on a single pipeline. The focus was particularly set on designing an intelligent node of a micro-irrigation system that can individually manage applicators. This required the development of a physical network for energy distribution and communication between applicators and individual nodes along the irrigation line. Development was supported by software for managing the main controller, communication devices and individual micro applicator nodes. A total of 50 nodes were deployed. Each node consisted of a micro-controller and an electrical circuit. The solenoid valves individually controlled the water flow on each applicator. A pressure sensor was used to monitor the pressure in the applicators. The applicator controller provided information and stored data for the irrigation schedule. The laptop was used to transmit the irrigation schedule and access the sensor data on the pipeline regulator. The results showed that the micro-irrigation system can be configured for varying irrigation according to the individual needs of each plant [43]. Fig. 4. displays a micro-irrigation system with a wireless network.

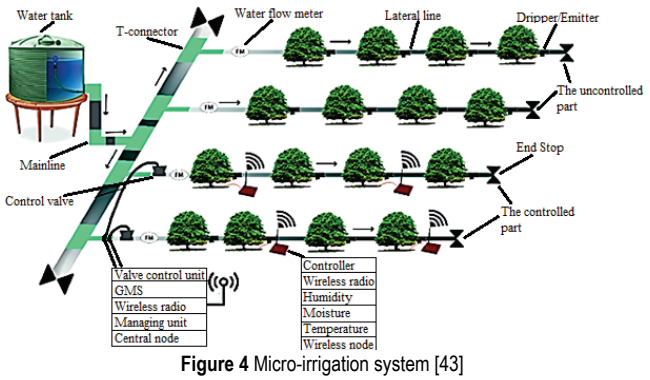


Figure 4 Micro-irrigation system [43]

That system operates on the principle of a wireless network. The sensor connected to the wireless node measures the soil moisture according to the set values and determined the irrigation starting period. The wireless controller measures soil moisture and temperature and using a built-in transmitter that sends information to the central node. The central node controls the solenoid valves and the node has a built-in receiver that receives information sent from the wireless node. The central node can be connected to a laptop, and can also be controlled via a mobile device using a GSM module. The controller in the central node processes the data according to the set values and thus manages the automatic micro-irrigation. Water pumps and associated solar panels for pumps can be installed on this system. It is possible to operate the controller via a mobile phone and to enter/export data obtained from the humidity sensor in real-time [43].

4 SENSORS AND METHODS OF DATA COLLECTION

The precision irrigation systems require accurate spatiotemporal data of soil and crop conditions in the field. They also require the ability to identify and quantify such data in order to apply appropriate irrigation. Various measuring devices for collecting data on soil moisture and plant water requirements are present. Spatial variability of the field can be measured: continuously (imaging in motion using a camera placed on pivot centers), discrete (point sampling of soil properties using soil moisture probes) and remotely (multispectral sensors mounted on unmanned aerial vehicles or satellites). A wide range of plant sensor technologies is available for the detection of plant stress. Crop monitoring technologies can be divided into two groups: contact sensors (provide detailed data for individual plants that are useful for understanding daily fluctuations) and remote (more suitable for collecting spatial data at the local or regional level and therefore more suitable for estimating spatial differences in plant loading and application in precision irrigation system). Such sensors typically measure plant responses associated with water intake, moisture evaporation, and plant growth rates. Variations in these measurements that indicate crop stress can be used in decision-making in precision irrigation. Crop sensors do not give any indication of water deficiency, so these methods should be used in combination with soil moisture measurements. Crop sensors typically have the ability to record and GNSS readings and can produce field measurement maps. There is also a wide range of satellite sensors from which data can be obtained for agricultural use [44-47].

4.1 Multispectral Sensors

Authors [44] noted that a wide range of sensors that can be used regardless of their distance to imaging object to measure the electromagnetic reflectance of the surface. Authors [45] provided a description of spectral bands that can be used to monitor soil variability. Data obtained in the spectral bands can usually be processed to highlight differences in crop conditions using the normalized difference vegetation index (NDVI). Various researchers have found a relationship between NDVI and crop coefficient for a wide range of crops. An alternative to using NDVI is to predict the actual evaporation of crops using remote energy balance research. According to [46, 47], both approaches support obtaining a large amount of data on crop water evaporation for irrigation management. Fig. 5. represents an example of the NDVI image in precision irrigation.

NDVI quantifies the vegetation by measuring the differences between the reflectance in the near-infrared band, NIR (which is strongly influenced by vegetation), and red band, RED (which is highly absorbed by vegetation). The NDVI was calculated according to formula (1) [48]:

$$NDVI = \frac{(NIR - RED)}{(NIR + RED)}. \quad (1)$$

Healthy vegetation with high chlorophyll content reflects more near-infrared and green wavelengths compared to other wavelengths but absorbs more red and blue wavelengths. The result of the formula (1) creates the values in the number interval between –1 and +1. If they are low in the *RED* band and high in the *NIR* band, *NDVI* will result in a value close to 1 and vice versa [48]. Thus, in the example displayed in Fig. 5, green pixels indicate healthy and dense vegetation while red pixels indicate a crop under water stress.

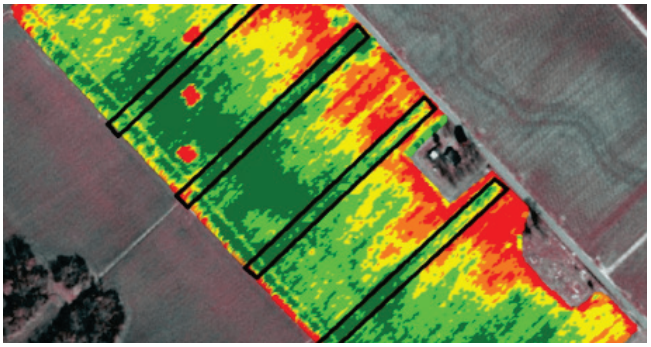


Figure 5 NDVI values for precision irrigation management [48]

Multispectral sensors are commonly implemented on satellites and unmanned aerial vehicles, which regularly achieve a higher spatial resolution [43]. In Fig. 6 an example of determining soil moisture and an irrigation map of the Ceres model is presented.

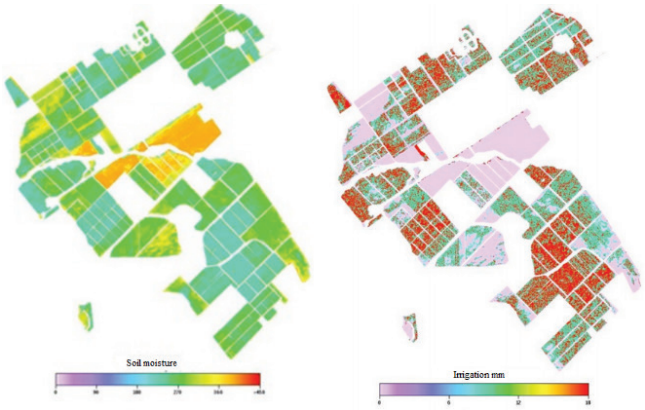


Figure 6 An irrigation map obtained using the Ceres model [34]

4.2 Thermal Sensors

Canopy cover temperature represents a relative measure of the water evaporation rate and indicates crop water stress. Infrared thermal cameras measure the radiation energy (temperature) of an object using thermal infrared wavelengths. The canopy cover temperature obtained by thermal sensors is compared with the crops without water stress for the calculation of crop water stress index (*CWSI*). *CWSI* is calculated according to formula (2) [34]:

$$CWSI = \frac{T_c - T_{wet}}{T_{dry} - T_{wet}}, \quad (2)$$

where: T_c represents vegetation temperature obtained from the thermal image; T_{wet} represents the lower temperature limit and T_{dry} represents the higher temperature limit. Thermal sensors and thermometers enable the creation of maps representing soil water content variations in the agricultural field. *CWSI* was developed in 1981 and was normalized to determine operates works on the principle of thermal infrared wavelengths and can be mounted on an unmanned aerial vehicle for aerial monitoring [50].

Fig. 7. displays the agricultural area divided into pixels with a *CWSI* value after imaging, which determines the amount of crop water deficiency. If the pixel value is 0, it indicates that the crop is not under stress and contains the optimal amount of water. If the pixel value is 1, the maximum crop water stress is present and the irrigation should be implemented or applied.

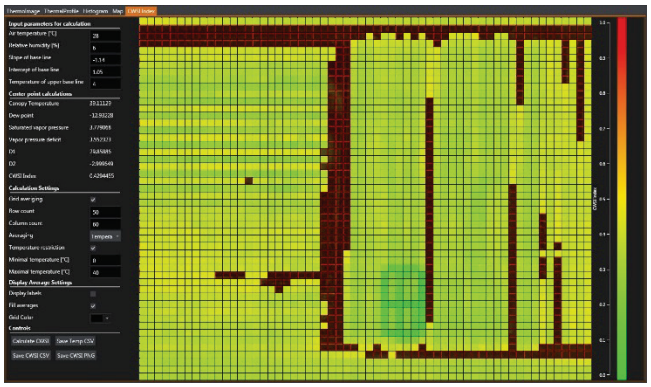


Figure 7 Display of *CWSI* values representing water stress after imaging [50]

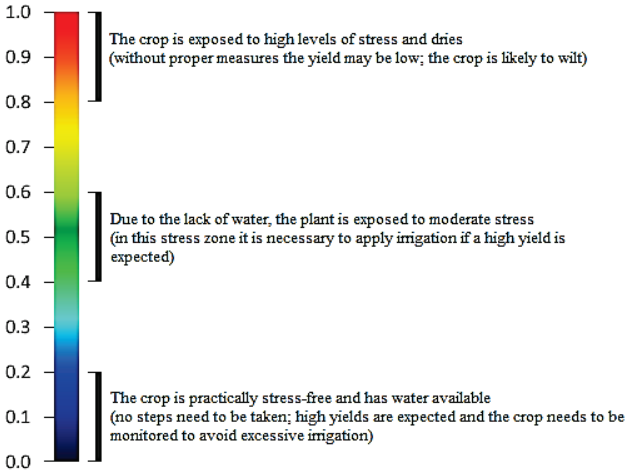


Figure 8 Crop water stress scale [50]

Fig. 8. displays an example of a crop water stress scale [50]. Authors [38] noted the irrigation schedule for the controlled pivot system and the drop-by-drop systems were controlled by the temperature-time threshold (TTT) method. The TTT method includes infrared thermal cameras that continuously measure the temperature of the plant cover. If the cover temperature rose by a predetermined value in a certain time, irrigation would be started.

5 CONCLUSION

The combination of crop and soil monitoring with appropriate growth simulation models is the first step of precision irrigation. Upgrading these models with the control and optimization systems of each irrigation system completes the precision irrigation system. These procedures rely on the ability to manage variations in individual plants' water balance.

There is no best universal precision irrigation system. Moving towards precision irrigation requires a system that can adapt to the existing conditions. It also implies the idea that the system will succeed in achieving a certain goal, like maximum water utilization, maximum yield, or maximum profitability.

The four important steps for precision irrigation are data collection, data analysis, control, and system evaluation. Precision irrigation systems require accurate and updated spatial data obtained by field measurement and collected using a variety of imaging sensors. The obtained data are interpreted and analyzed by computer software to aid in decision making. Precision irrigation can potentially increase economic efficiency through optimal irrigation in each part of the field according to crop requirements and thus reduce costs.

According to available data in the Republic of Croatia, irrigation is not significantly developed and amounts to only 0.46% of the agricultural area (less than 10 000 ha). There are the most suitable soils for irrigation in Osijek-Baranja and Vukovar-Srijem counties. According to the available quality and quantity of water, Croatia can irrigate about 30% of arable land or about 600 000 ha.

6 REFERENCES

[1] Gereš, D. (2002). Sustainable use of water in Croatia and in Europe. *Građevinar, 54*(6), 345-353.

[2] Šimatović, J. (2012). Application of GIS systems in crop production - Precision Agriculture. *Bsc Graduation thesis*. Faculty of Agriculture Osijek, University of Josip Juraj Strossmayer in Osijek.

[3] Goovaerts, P. (2000) Geostatistical approaches for incorporating elevation into the spatial interpolation of rainfall. *Journal of Hydrology, 228*(1-2), 113-129. https://doi.org/10.1016/S0022-1694(00)00144-X

[4] Jurišić, M., Stanisavljević, A., Plaščak, I. (2010). Application of Geographic Information System (GIS) in the selection of vineyard sites in Croatia. *Bulgarian Jorunal of Agricutural Science, 16*(2), 235-242. https://www.researchgate.net/publication/267692739_Application_of_Geographic_Information_System_GIS_in_the_selection_of_vineyard_sites_in_Croatia

[5] Vukadinović, V. (2016). Soil, fertilization and yield. *Own edition*, Osijek.

[6] Mađar, S. & Šoštarić, J. (2009). *Irrigation of agricultural crops*. Faculty of Agriculture in Osijek.

[7] Mulla, D. J. (2013). Tventy five years of remote sensing in precision agriculture: Key advances and reaming knowledge gaps. *Biosystems Engineering journal, 114*(4), 358-371.

[8] Proulx, S., Sri Ranjan, R., & Klassen, G. (1998). Evaluation of soil moisture sensors in potato fields. *1998 North Central Region Intersectional Meeting, South Dakota,* 1-17. https://www.researchgate.net › download › nordak

[9] Marković, M. (2013). Influence of irrigation and nitrogen fertilization on yield and quality of maize (Zea mays L.) grain. PhD thesis. *Faculty of Agriculture in Osijek*, *University of Josip Juraj Strossmayer in Osijek.* https://drive.google.com/file/d/0B70wpjq3L39CaF9qc2x0SF9QQjQ/view

[10] Brevik, E. C., Fenton, T. E., & Lazari, A. (2006). Soil electrical condutivity as a function of soil water content and implications for soil mapping. *Precision Agriculture, 7,* 393-404. https://doi.org/10.1007/s11119-006-9021-x

[11] Huđek, J. (2014). Monitoring of soil moisture content with tdr device irrigation scheduling. *Master thesis*. Faculty of Agriculture in Osijek, University of Josip Juraj Strossmayer in Osijek.

[12] Pereira L. S. & Trout T. J. (1999.) Irrigation methods in: cigr handbook of agricultural engineering. Handbook. *American Society of Agricultural Engineers*. https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&cad=rja&uact=8&ved=2ahUKEwjjxeaetdrwAhWYHuwKHWFWBp4QFjABegQIAxAD&url=https%3A%2F%2Felibrary.asabe.org%2Fcigr_handbook.asp%3Fconfid%3Dcigr1999&usg=AOvVaw2R0LvaornAcB42kLoJl_NU

[13] Evans, R. G., Han, S., Kroeger, M. W., & Schneider, S. M. (1996). Precision centre pivot irrigation for efficient use of water and nitrogen. *Precision Agriculture, Proceedings of the 3rd International Conference, Minneapolis, Minnesota,* 75-84. https://doi.org/10.2134/1996.precisionagproc3.c8

[14] Kincaid, D. C., Buchleiter, G. (2004). Irrigation, Site-Specific. *Encyclopedia of Water Science,* 1-4. https://doi.org/0.1081/E-EWS 120010137

[15] Al-Karadsheh, E., Sourell, H. & Krause, R. (2002.) Precision Irrigation: New strategy irrigation water management. *Conference on International Research on Food Security, Natural Resource Management and Rural Development, Deutscher Tropentag, Witzenhausen, 11-22.*

[16] Camp, C. R., Sadler, E. J., & Evans, R. G. (2006). Precision Water Management: Current Realities, Possibilities and Trends. *Handbook of Precision Agriculture. Binghamton, New York: Haworth Press.,* 153-183.

[17] Chavez, J. L., F. Pierce, F. J., Matthews, G. R., Elliot, T. V., Evans, R. G., & Kim, Y. (2006). Performance of a continuous move irrigation control and monitoring system. *2006 ASABE Annual International Meeting, Oregon,* 062163. https://doi.org/10.13031/2013.20733

[18] King, B. A., Stark, J. C., & Wall, R. W. (2006). Comparison of site-specific and conventional uniform irrigation management for potatoes. *Applied Engineering in Agriculture, 22*(5), 677-688. https://doi.org/10.13031/2013.22000

[19] Sadler, E. J., Evans, R. G., Stone, K. C., & Camp, C. R. (2005). Opportunities for conservation with precision irrigation. *Journal of Soil and Water conservation, 60* (6), 371-379.

[20] Peters, R. T. & Evett, S. R. (2004). Complete center pivot automation using the temperature-time threshold method of irrigation scheduling. *2004 ASAE/CSAE Annual International Meeting, Ottowa, Ontario, Canada,* 042196. https://doi.org/10.13031/2013.16409

[21] O'Shaughnessy, S. A., Evett, S. R., Coliazzi, P. D., & Howell, T. A. (2008). Soil water measurement and thermal indices for center pivot irrigation scheduling. *Irrigation Association Conference Proceedings Anaheim, California,* 23-33.

[22] Yule, I. J., Hedley, C. B., & Bradbury, S. (2008). Variable-rate irrigation. *12th Annual Symposium on Precision Agriculture Research & Application in Australasia, Sydney,* 24-26.

[23] Hedley, C. B. & Yule, I. J. (2009). Soil water status mapping and two variable-rate irrigation scenarios. *Precision Agriculture, 10*, 342-355. https://doi.org/10.1007/s11119-009-9119-z

[24] King, B. A., Wall, R. W., Kincaid, D. C., & Westermann, D. T. (2005). Field testing of a variable rate sprinkler and control system for site-specific water and nutrient application. *Applied Engineering in Agriculture, 21*(5)*,* 847-853. https://doi.org/10.13031/2013.19712

[25] DeJonge, K. & Kaleita, A. (2006). Simulation of spatially variable precision irrigation and its effects on Corn growth using CERES-Maize. *ASABE Annual International Meeting, St. Joseph, Michigan,* 062119. https://doi.org/10.13031/2013.20710

[26] Lu, Y. C., Sadler, J. E., & Camp, C. R. (2005). Economic feasibility study of variable rate irrigation of corn production in southeast coastal plain. *Journal of Sustainable Agriculture, 26*(3)*,* 69-81. https://doi.org/10.1300/J064v26n03_08

[27] Heerman, D. F., Hoeting, J., Thompson, S. E., Duke, H. R., Westfall, D. G., Buchleiter, G. W., Westra, P., Peairs, F. B., & Fleming, K. (2002). Interdisciplinary irrigated precision farming research. *Precision Agriculture, 3,* 47-61. https://doi.org/10.1023/A:1013374120356

[28] Almas, L. K., Amosson, S. H., Marek, T., Colette, W. A. (2003). Economic feasibility of precision irrigation in the northern Texas high plains. *Southern Agricultural Economics Association Annual Meeting. Mobile, Alabama,* 1-15.

[29] Gillies, H.M. (2008). Managing the effect of infiltration variability on the performance of surface irrigation. Dissrtacion. *Faculty of Engineering and Surveying, University of Southern Queensland.*

[30] Bautista, E., Clemmens, A. J., Strelkoff, T. S., Schlegel, J. (2009). Modern analysis of surface irrigation systems with WinSRFR. *Agricultural Water Management, 96*(7)*,* 1146-1154. https://doi.org/10.1016/j.agwat.2009.03.007

[31] Austin, N. R., Prendergast, J. B. (1997). Use of kinematic wave theory to model irrigation on cracking soil. *Irrigation Science, 18*, 1-10. https://doi.org/10.1007/s002710050038

[32] Khatri, K. L., Smith, R. J. (2006). Real-time prediction of soil inflitration characteristics for the managment of furrow irrigation. *Irrigation Science, 25,* 33-43. https://doi.org/10.1007/s00271-006-0032-1

[33] Lam, Y., Slaughter, D. C., Wallender W. W., Upadhyaya, S. K. (2007). Machine vision monitoring for control of water advance in furrow irrigation. *Transactions ASABE, 50*(2)*,* 371-378. https://doi.org/10.13031/2013.22628

[34] Smith, R. J., Baillie, J. N., McCarthy, A. C., Raine, S. R., & Baillie, C. P. (2010). Review of Precision Irrigation Technologies and theri Application. *Toowoomba, Australia: National Centre for Engineering in Agriculture University of Southern Queensland Toowoomba,* 1003017/1.

[35] Cape, J. (1998). Using software to review sprinkler performance. *Irrigation Australia, 13*(3)*,* 18-20.

[36] Smith, R. J., Gillies, M. H., Newell, G., & Foley, J. P. (2008). A decision support model for travelling gun irrigation machines. *Biosystems Engineering, 100*(1)*,* 126-136. https://doi.org/10.1016/j.biosystemseng.2008.01.004

[37] McCarthy, A. C., Hancock, N. H., & Raine, S. R. (2010). VARIwise: A general-purpose adaptive control simulation framework for spatially and temporally varied irrigation at sub-field scale. *Computers and Electronics in Agriculture, 70*(1)*,* 117-128. https://doi.org/10.1016/j.compag.2009.09.011

[38] Peters, R. T. & Evett, S. R. (2006). A fully Automated Center Pivot Using Crop Canopy Temperature. *USCID Water Managment Conference*, *Boise, Idaho*, 139-148.

[39] Evans, R. G., Kim, Y., & Iversen, W. M. (2007). Evaluation of closed-loop irrigation control with wireless sensor network.

2007 ASABE Annual International Meeting, Minneapolis, Minnesota, 072248. https://doi.org/10.13031/2013.23374
[40] Evett, S. R., Peters, R. T., & Howell, T. A. (2006). Controlling water use efficiency with irrigation automation: cases from drip and center pivot irrigation of corn and soybean. *Southern Conservation Systems Conference, Amarillo TX,* 57-66.
[41] Capraro, F., Patino, D., Tosetti, S., & Schugurensky, C. (2008). Neural network-based irrigation control for precision agriculture. *IEEE International Conference on Networking, Sensing and Control, Sanya, China,* 357-362.
[42] Coates, R., Delwiche, M., & Brown, P. (2006). Design of a system for individual microsprinkler control. *Transactions of the ASABE, 49*(6)*,* 1963-1970. https://doi.org/10.13031/2013.22276
[43] Barman, A., Neogi B., & Pal, S. (2020). Solar-Powered Automated IoT-Based Drip Irrigation System. *IoT and Analytics for Agriculture. Studies in Big Dana, Springer, Singapore,* 27-49. https://doi.org/10.1007/978-981-13-9177-4_2
[44] Bastiaanssen, W. G. M., Molden, D. J., & Makin, I. W. (2000). Remote sensing for irrigated agriculture: examples from research and possible applications. *Agricultural Water Management, 46(2),* 137-155. https://doi.org/10.1016/S0378-3774(00)00080-9
[45] McBratney, A. B., Mendonca Santos M. L., & Minasny, B. (2003). On digital soil mapping. *Geoderma, 117*(1-2)*,* 3-52. https://doi.org/10.1016/S0016-7061(03)00223-4
[46] Gowda, P. H, Senay, G. B., Howell, T. A., & Marek, T. H. (2008). Lysimetric Evaluation of Simplified Surface Energy Balance Approach in the texas high plains. *Applied Engineering in Agriculture, 25*(5)*,* 665-669. https://doi.org/10.13031/2013.28855
[47] Chavez, J. L., Gowda, P. H., Howell, T. A., & Copeland, K. S. (2009). Radiometric surface temperature calibration effects on satelite based evapotranspiration estimation. *International Journal of Remote Sensing, 30(9),* 2337-2354. https://doi.org/10.1080/01431160802549393
[48] Precision Agriculture (2018). NDVI and satellite crop monitoring. Retrieved from https://precisionagricultu.re/ndvi-and-satellite-crop-monitoring/
[49] Hossain, B. (2008). EM38 for measuring and mapping soil moisture in a cracking clay soil. *PhD Thesis*. University of New England, Armidale.
[50] Medicas (2020). Thermal screening of diseases. Retrieved from https://www.workswell-thermal-camera.com

Authors' contacts:

Ivan Plaščak, PhD, Associate Professor
Faculty of Agrobiotechnical Sciences Osijek
Vladimira Preloga 1, 31000 Osijek, Croatia
iplascak@fazos.hr

Mladen Jurišić, PhD, Full Professor
Faculty of Agrobiotechnical Sciences Osijek
Vladimira Preloga 1, 31000 Osijek, Croatia
mjurisic@fazos.hr

Dorijan Radočaj, MSc, Assistant
Faculty of Agrobiotechnical Sciences Osijek
Vladimira Preloga 1, 31000 Osijek, Croatia
dradocaj@fazos.hr

Milan Vujić, MSc
Faculty of Agrobiotechnical Sciences Osijek
Vladimira Preloga 1, 31000 Osijek, Croatia
vujic.milan94@gmail.com

Domagoj Zimmer, PhD, Postdoc
(Corresponding author)
Faculty of Agrobiotechnical Sciences Osijek
Vladimira Preloga 1, 31000 Osijek, Croatia
dzimmer@fazos.hr

ISSN 1846-6168 (Print), ISSN 1848-5588 (Online)
https://doi.org/10.31803/tg-20210628194103

Subject review

The Metaphorical Culturalistic Approach to Technology Assessment

Patricia Girrbach

Abstract: This paper aims to demonstrate that technology assessment (TA) must be seen in a new enhanced culturalistic way cause cultural aspects determine TA in an incremental way. Therefore, it is important to analyze how the process of TA depends on cultural influences. Moreover, it is important to show how to handle this problem due to the fact that TA aims to be objective instead of cultural determined and normative. Therefore, the objective of this paper is to create a new way of reflecting TA, to show impulses for non-normative ethics in technology assessment and to present the new enhanced metaphorical culturalistic approach (MCA) of technology assessment.

Keywords: metaphorical culturalistic approach; non-normative ethics; technology assessment

1 INTRODUCTION

Digitalization is the essential basis for today's industry 4.0 [1]. In this context new technologies enable a new level of production including a total transformation of processes along the entire value chain of firms. These new technologies include for example well known technologies such as Internet of Things, Smart Manufacturing or Cyber Physical Systems which are crucial for nowadays industry. Based on these new technologies industry 4.0 paves the way to a new technological age including not only the incremental transformation of production, value chains and business models but also raising the way of consumption to a new level. Since new technologies can shape whole societies, it is very important to take care of their possible future drawbacks already in the development process [5]. Therefore, the crucial question of each new technology is, are there more positive effects on society than negative. Concerning this issue technology assessment (TA) comes into play focusing especially on the chances and risks arising out of a new technology [2, 5]. Therefore, TA influences industry 4.0, in detail the technologies used. This is caused in the reason that only if technologies are assessed as useful and not dangerous for the environment (pollution or unacceptable risks which should be averted) or the society (e.g., in terms of aspects such as the health or privacy of people that should be protected) they will be produced and applied in industry. Consequently, there is a great interdependency and a high impact of TA on technologies used in industry 4.0 (Fig. 1).

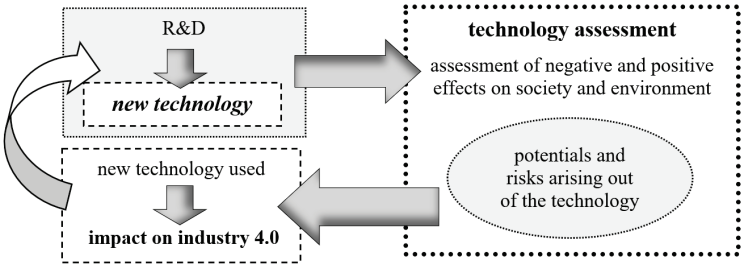


Figure 1 The impact of TA (own figure)

2 TECHNOLOGY ASSESSMENT

TA can be understood as the research on technology [2, 5, 11]. Hereby technology contains not only the conception, and production but also further important aspects such as the use of the technology, the disposal as well as its institutional and organizational framework conditions [3]. Moreover, TA can be considered as problem-oriented research regarding methods as well as results in the context of their actual assignment and principals [2, 5]. Finally, TA is a scientific consulting practice offering updated well-founded orientation knowledge based on its experience with technology-induced social conflicts [2, 5, 11]. The subject is detecting and analysing not only specified goals or means but also potential un-/acceptable consequences for the society or environment rising out of a new technique [4, 5, 11]. Thus, the key question of predictive TA focuses on the consequences of technical interventions on the natural as well as the related socio-cultural environment [5]. To decide the tolerable depth of future intervention in natural cycles it is important to consider both negative un-/certain consequences of technical interventions as well as the intensity of the desired effect for given social purposes [5]. In this context various participants often rate the risks and chances of a new technology differently caused in two possible reasons [6]:

- The first reason is that participants of the TA process often start from different descriptive prerequisites, therefore their assessment in terms of actual limits, possibilities, or the specific design of future applications is different [6].
- A possible second reason can be that participants of the TA process presume various normative prerequisites; in

this case they evaluate the expected consequences of the technology application presented based on different value systems (their normative orientation) differently [6]. It is obvious that this can lead to value conflicts during the TA process [6, 7].

Therefore, technology research requires not only the knowledge of the consequences of the respective interventions as part of scientific and technical risk research but also and even more important the knowledge in terms of the desirability and ethical justification of these interventions by society [5]. This includes a comprehensive debate on issues of the environmental impact (regarding environment as a kind of cultural asset) and a potential desirable change in current socio-cultural systems [5]. Thus, TA can be described as cultural science for several reasons. Especially any technology is not primarily problematic from the technical aspect of its functioning, but rather regarding its cultural significance and the specific evaluation of the consequences according to the culture and implicit cognitive models of participants. Thus, technology conflicts are determined by normative and cultural aspects such as conflicts about ideas about the future or concepts of society in an incremental way [5]. This is caused in the reason that what is socially desirable or acceptable is usually controversial depending on the cultural background of people [6, 8, 13] (Fig. 2). Therefore, according to the socio-ecological approach of TA problems are always defined socially and in consequence culturally [5, 6, 8].

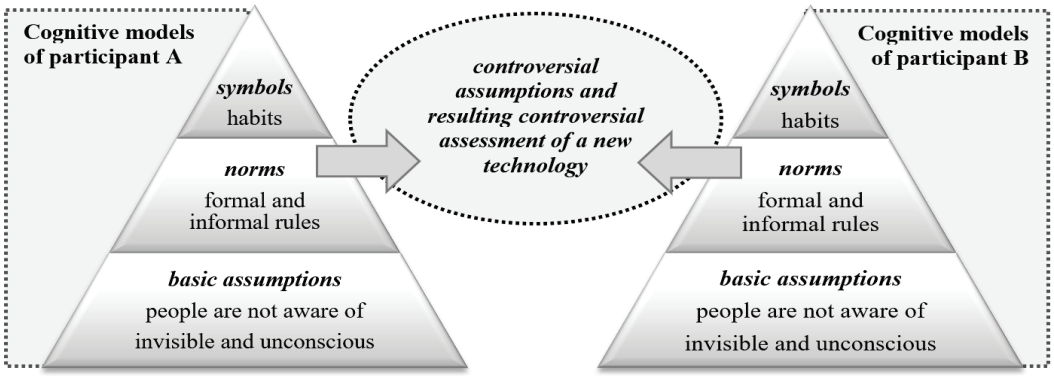


Figure 2 Controversial assumptions caused in different cognitive models (own figure based on Schein [10])

3 INTERDEPENDENCES BETWEEN ETHICS, NORMATIVITY AND TA

Ethics is the reflection of values and norms as well as the underlying assumptions [9]. Hereby, descriptive ethics describes and explains existing morals including formal (e.g., law) and informal rules of a society. Therefore, the subject of the research interest is the objective description & explanation of existing values & norms of a social group as well as the inclusion of underlying ethical principles. These underlying ethical principles are important to understand the existing morality of a society in a certain time. In contrast to that normative ethics assesses current morals and gives recommendations for improvements and better behaviour from a moral point of view [9]. In consequence normativity can be understood as a statement in which a specific evaluation is expressed [e.g., honesty is good and desirable]. In this context normative ethics tries to develop well-founded normative principles that are intended to serve as orientation and recommendation for action or regulative idea to guide individual as well as collective behaviour in a certain manner.

In addition to ecological, social, legal, or economic aspects, cultural and thus ethical and normative questions play an important role in TA [5, 6, 13]. Thus, TA is accompanied by a normative charge since normative elements as well as decisions can be identified at three levels of all TA processes [7, 13, 14, 15]:

1) The context of the TA process (e.g., presumptions, working method, selected participants of the TA process)
2) The function of TA as political advice (e.g., content of the advice, the subject such as ecological consequences or even the choice of the new technology)
3) The normative core of TA (in detail e.g., the prioritized objective of sustainability or the priority of social objectives and issues over economic ones)

So, we can identify different types of normative aspects concerning TA [7, 13, 14, 15]. On the one hand there are implicit value references of TA such as in-normativity [15]. In-normativity includes values and norms of the participants taking part in the TA process. On the other hand, meta-normativity comprises fundamental inherent goals of TA such as the claim for a healthy environment, the protection of privacy or sustainability as objective, as well as the often-mentioned TA's obligation to inclusion and a democratic debate containing the well-known presumption that a more pluralistic process will always produce better outcomes than another procedure [2, 13, 15, 16]. Other examples for further inherent and normative determined aspects of TA are the choice of a certain technology (the technology itself, e.g., delivery drones or robots that should be evaluated), focused areas that should be analysed in terms of the new technique as well as the selected actors involved [13].

Beside that there are also central explicit normative guiding principles of TA such as sustainability, social justice, and human rights that provide a normative framework for the assessment of new technologies [13, 16]. So, we can conclude that culture and value references determine TA in general as well as its procedures, e.g., used scientific-

technical knowledge, concepts, goals, procedures, and consequently also the results of the TA process [13]. Accordingly, culture determines how we look at a new technology (e.g., delivery drones or robots) [5, 6].

Therefore, the augmented *metaphorical culturalistic approach* (MCA) of TA contains a new way of looking at TA. It enhances former approaches by using the metaphor of cultural glasses to point out the direct interdependence of culture in terms of our assessment. Thus, our cultural-colored glasses determine how we perceive things. Depending on the culture, the glasses have a different color. It is the same as looking at a yellow lemon with blue glasses. The result is you see the lemon green (according to traffic lights green implies e.g., the technology is accepted as useful). If your glasses are red, the lemon seems to be orange (orange implies e.g., the new technology is not accepted as useful). In this example the lemon stands for a new technology that is assessed in different ways due to different cultural assumptions (Fig. 3).

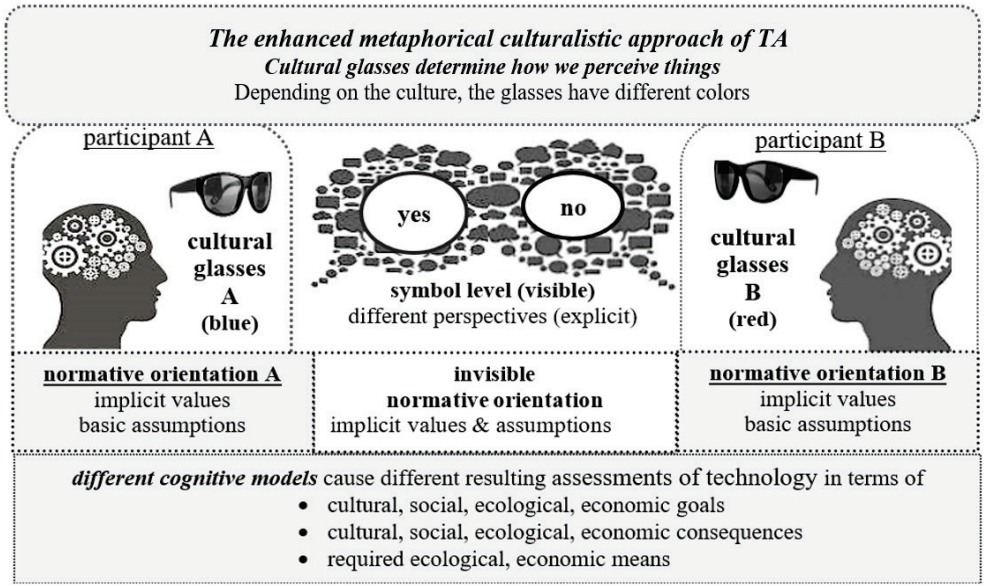


Figure 3 The enhanced metaphorical culturalistic approach of TA: Cultural glasses determine how we perceive things (own figure)

We can estimate that normativity in TA exists because it cannot be neglected that normative elements and resulting decisions can be identified at all levels and along the entire TA process [13]. In addition to ecological, social, legal, or economic aspects, cultural and thus ethical and normative questions play an important role in TA [5, 8, 13]. The crucial problem is this shatter the often-mentioned claim of TA to neutrality and non-normativity [13, 14]. Therefore, it contradicts the TA's demand for neutrality focusing a competent, neutral assessment of the possible advantages and disadvantages of new technologies [13, 17]. So, the question is how to deal with this existing normativity and are there any possible solutions?!

4 FOCUSING THE INVISIBLE

The underlying idea of the approaches shown in this paper is to replace the existing implicit normativity by reflexive normativity aiming to enable TA to reflect, describe, explain, and analyze the current normative structure of technology conflicts [13]. In the sense of reflexive normativity TA should provide a helpful contribution to the clarification of the normative level, including decision-making processes in terms of inherent goals, or the acceptability of resulting consequences for the whole society, affected people or the environment [13]. Thus, the concept of reflexive normativity does not negate normative influences of TA rather it opens the TA process and inherent normative determined assumptions for a productive discursive debate [6, 13]. That is important since the aim is to increase procedural neutrality. Moreover, the purpose is the identification and disclosure of normative premises at all levels of TA and a systematic, method-based analysis of the value references which are relevant within each TA process. Reflexive normativity focuses on the value systems on which research is based to identify in- and explicit presuppositions for the sake of a greater transparency in terms of normative aspects [13]. Moreover, the aim is to justify the research underlying value systems with reasoned arguments for e.g., selected goals. This offers the chance and possibility to take responsibility for them. Thus, reflexive normativity aims to make values and normative preliminary decisions of TA processes transparent and more manageable [13] (Fig. 4).

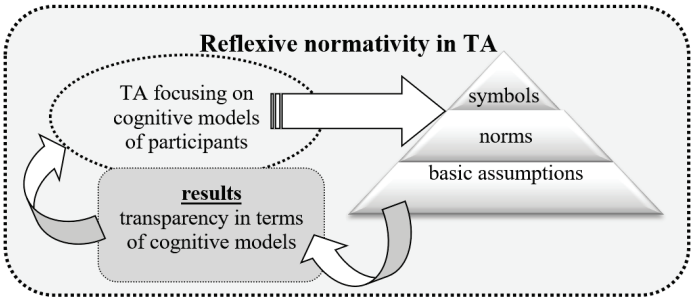


Figure 4 Focusing cognitive models in TA processes (own figure)

So, we can summarize that the aim of reflexive normativity is to utilize the outcomes for balancing one-sided selections in favor of a greater plurality of positions and heterogeneous perspectives in TA processes [6, 13]. Consequently, reflexive normativity replaces neutrality which is always only fictitious with the constant awareness of normative references under which TA is carried out to avoid or at least to minimize the often-unconscious selectivity in the TA process which contradicts the aim of neutrality [13, 17]. There are several practices of reflexive normativity that can be used in the context of TA [6, 13]: The first starting point is to establish and operationalize reflexivity by the introduction of specific standards, rules for transparent procedures, or Codes of Conduct. Moreover, the involvement of supervisors can be useful at a very early stage who critically question the entire procedure of the project as well as underlying assumptions. So, a continuous reflection of current premises and methods along the entire process is required. Research diaries or reflexive journals can be helpful to document the research process by noting normatively relevant questions permanently and reflecting them critically, to make the path and choices made by participants more transparent, visible, and thus traceable [13]. This enhances the objectivity of the TA itself. Furthermore, the inclusion of further actors from the field of governance is recommended to change innovation trajectories in the sense of promoting the common good. To enhance the heterogeneity of opinions and to include knowledge from different areas, at best, actors such as natural, social, as well as human sciences should already communicate during development in the laboratory. Moreover, normative guiding principles and resulting ideals driving scientific research should be disclosed to support the reflection of laboratory scientists in terms on the socio-ethical context. Finally, the inclusion of other potentially affected parties in the process of technological development is crucial to improve and enrich the process of development of the technology itself early [2, 13, 16]. By using these methods of reflexive normativity, the transparency of cognitive models and resulting normative orientations can be enhanced. Especially in participative processes these techniques are useful to gain a broader holistic view in terms of the assessment of new technologies and to understand upcoming controversial discussions (see Fig. 5).

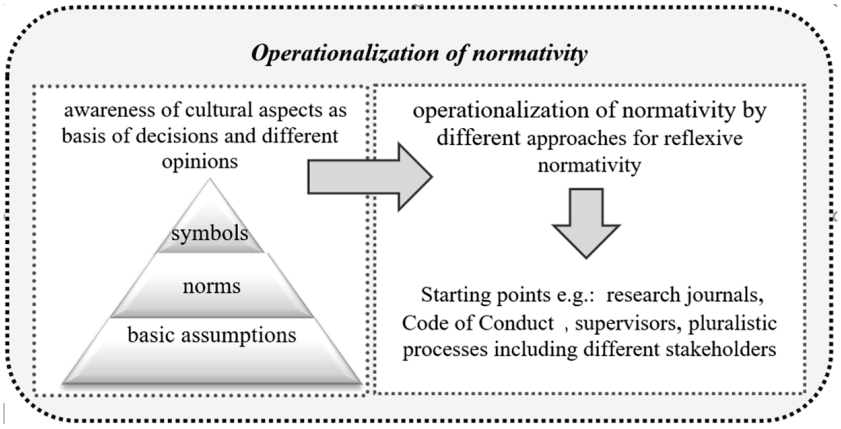


Figure 5 Operationalization of normativity of TA (own figure)

There is no doubt that participation processes are essential for reflexive normativity [6, 13]. Hereby, participants using different cognitive models, often assess differently the desirability of new technologies (e.g., robots) without recognizing why they disagree in this context [6]. This lake of understanding each other must be closed. Otherwise, an opportunity to understand each other and to reflect on one's own point of view is wasted [6]. But especially this reflection is crucial to support constructive discussions for the sake of better outcomes, to understand each other and to bring the points of different views closer together [6, 13]. Since participants do often not have a common vocabulary with which they can explicitly express their values a common vocabulary is needed especially in participatory processes with a greater number of participants with different cultural and scientific background [6]. A common vocabulary serves as a basis for understanding each other and gaining transparency regarding the values of the participants. How this can look like, will be explained in the following chapter as part of the LOTA method [6].

5 METHODS FOR REFLEXIVE NORMATIVITY

The LOTA method [Landscape of Opinions for Technology Assessment] is intended to help involved participants with different background to recognize the reasons why they assess the opportunities and risks of a new technology differently [6]. The method supports discussion in participatory TA by capturing normative orientations of the participants to create transparency and to promote understanding [6]. LOTA uses a special software also called LOTA to evaluate, and to visualize data [6]. Data is collected through an online survey in which respondents answer questions about the new technology. Hereby, the selection and prioritization of the targets takes place in step 1. This is done by answering questions on the assessment of the urgency and long-term validity of the presumed goals and on the assessment of the opportunities and risks of the technology in relation to the selected goals. Participants must subjectively assess risks and opportunities arising in their opinion for the various goals, such as safety [6]. The software

tool evaluates the results of the research and visualizes them in diagrams. These are created for each person so that each participant can see his or her rating compared to the average of the participants of the process. Then, data is aggregated into an opinion landscape of participants that serves as a discussion starting point [6]. In the following the procedure of the LOTA method will be described.

The starting point for the online survey is a common vocabulary that serves as a basis for understanding the value foundations of the TA process [6]. But is it possible to reach agreement on a shared ethos of TA? LOTA solves this problem through an orientation towards values with already global approval. Thus, the underlying idea is to extract the vocabulary from already existing documents that have emerged from a broad-based political process [6]. In this context two important sources are for example the United Nations Sustainable Development Goals as well as the Universal Declaration of Human Rights [6]. In terms of the objectives there is no restriction to local or national contexts instead the objectives are global which implies a conscious normative setting caused in the reason that TA is understood in such a way that future consequences of a new technique (e.g., robots or drones) should be regarded for the entire planet [6]. Target systems are brought into the process; therefore, they are not normatively presupposed. Moreover, all participants have the chance to decide explicitly for or against the goals what increases transparency in terms of underlying normative models. In case participants cannot find the topic relevant to them in the given system, they even can formulate their own goal and add it to the system. In the following the different steps & process phases of the LOTA method will be described in detail with delivery drones as new technology which has to be assessed [6].

Step 1 is an online survey: In this first step participants select and prioritize the goals and answer further questions to assess the urgency and long-term validity of the objectives as well as the opportunities and risks of the delivery drones in relation to the goals selected before [6]. Obviously, there is an abstraction gap between general global goals and the respective technology (in this case delivery drones). This gap is filled by the individual assessment of the participants without any presumed guidelines only determined by the personal underlying value systems [6].

Step 2: In the next step the evaluation of the online survey takes place where the results of the survey are visualized for each participant in radar diagrams focusing the risks and chances as well as the level of concern in terms of the different goals such as securing the basic needs [6]. To increase transparency in terms of own and other implicit assumptions participants can see the own assessment colored black and the average assessment of the others coloured green. The following figure addresses chances and risks of the new technology in detail delivery drones due to the opinions of participants (Fig. 6) [6].

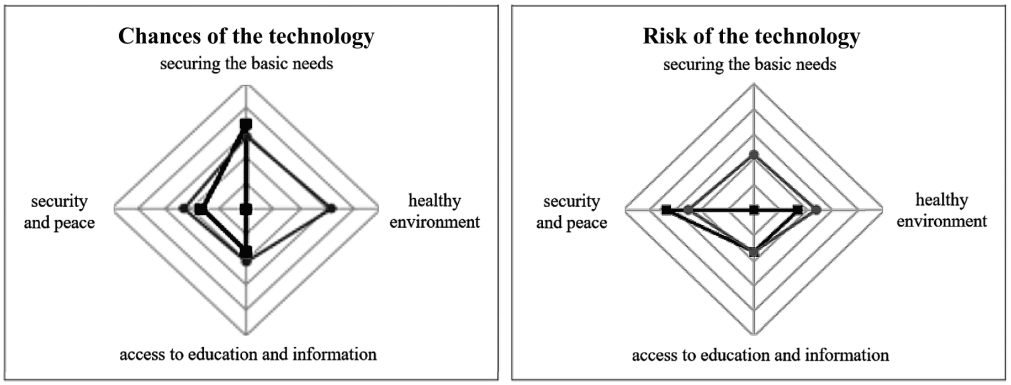


Figure 6 Radar diagrams in the TA – focusing on risks [6]

Afterwards a pseudonymized opinion landscape based on a cluster analysis is created [6]. The numerical values of the Cluster plot stand for the different participants of the survey. To save the privacy of the participants their names are pseudonymized in the Cluster plot. The moderator can use this representation to select the people to participate in the further process of TA whereby at least one person from each cluster should participate to raise the heterogeneity of different views and opinions [6]. Thus, this process increases not only the plurality of opinions, heterogeneity and diversity in the process but also promotes a more holistic view of TA.

Step 3: The third step contains a second online survey [6]: Based on the selected goals that had the highest subjective relevance for the participants the LOTA system creates a new updated list. Then all participants of the future workshop are asked once again in terms of the goals from the other actors that they had not selected themselves before. These goals are new to the combined and updated list. Beside the questions from phase I, actors are questioned about the goals and their interaction in detail. Then, the results of step 3 are visualized as an impact graph (Fig. 7) [6].

Step 4: The impact graph is important to serve as starting point of the workshop visualizing the following information based on the opinion of the participants [6]: Target system and relevance of the targets (node size), mutual influence (arrows), influence of the technology discussed, strength of influence (arrow thickness), and standard deviation via brightness. Thus, this impact graph can be understood as a visualization of the current opinion landscape of the participants of the TA process. Since it visualizes the existing heterogeneity of opinions it creates a greater awareness of the diversity of opinions due to different normative backgrounds and supports transparency as well as a common understanding during the TA process [6].

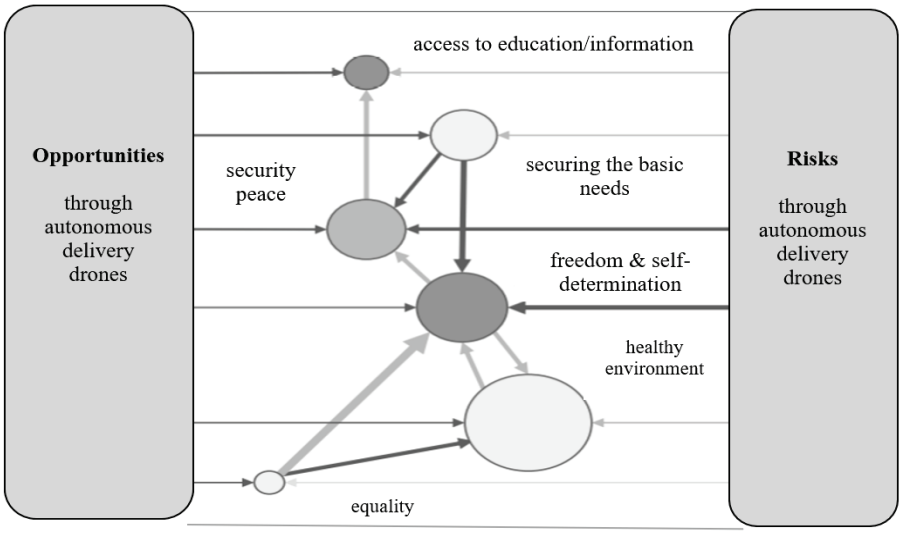


Figure 7 Impact graph (based on [6])

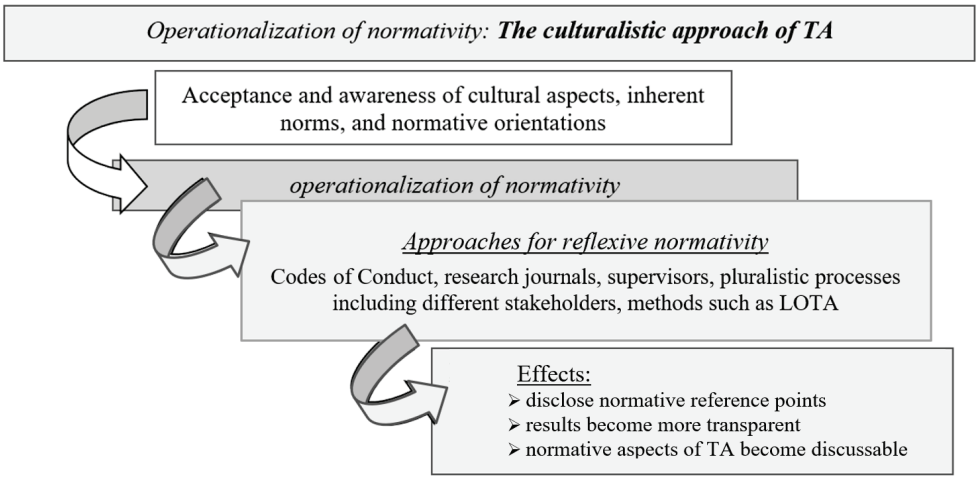


Figure 8 The culturalistic approach of TA (own figure)

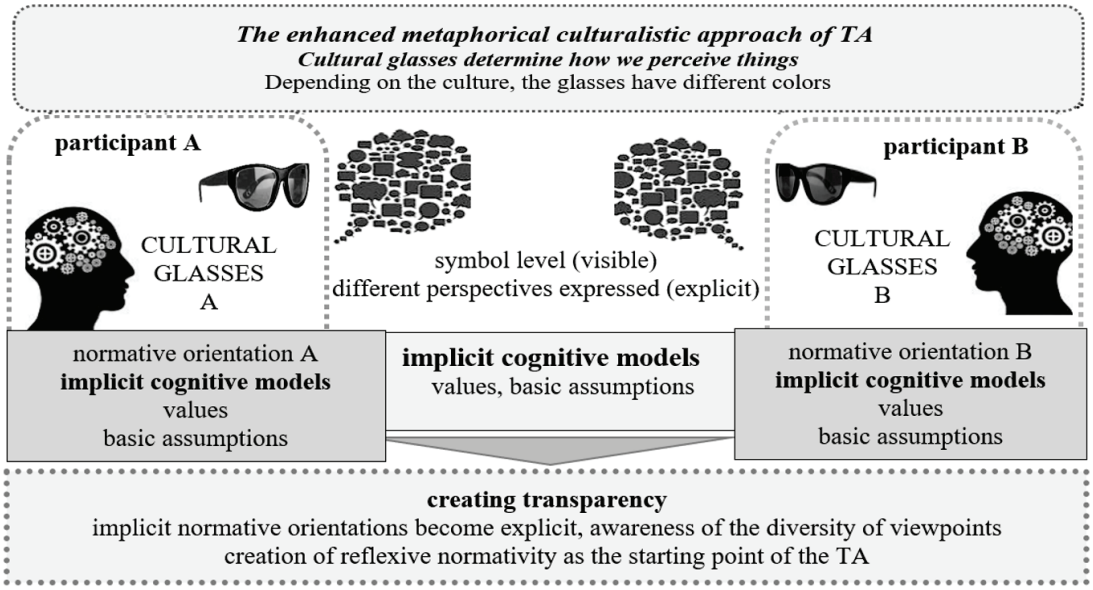


Figure 9 The enhanced metaphorical culturalistic approach (MCA) (own figure)

Participatory TA projects bring together people not only with different scientific background but even more important with different normative orientations caused in the heterogeneity of people [6]. Therefore, it is important to face this problem and to handle it by constructive procedures such as the described LOTA method [6]. In this context we can state that LOTA serves as a methodological approach aiming to support participants in dealing with the plurality of values in a transparent and traceable way [6]. Therefore, LOTA discloses different views, creates transparency and understanding for other opinions and assessments, and prepares participants for the following discussion. Although global goals as a normative frame of reference are presented the participants cannot only express their normative orientations by prioritizing presumed goals but even enhance them due to their own normative orientation [6]. Since a landscape of opinions pointing out different views is created, the LOTA method operationalizes normativity, discloses normative reference points and makes results more transparent for all participants [6]. Consequently, inherent normative aspects of TA become discussable. This significantly increases the quality of the TA process. Therefore, the LOTA method serves as a practical tool to put the *metaphorical culturalistic approach* (MCA) into practice (Fig. 8 & 9).

6 CONCLUSION

Today we are facing an incremental digital revolution based on new technologies offering chances and risks for the whole society including global consequences [1]. In these times TA becomes even more important than ever. Therefore, the aim of this paper is to point out an existing incremental issue in terms of TA in detail the claim for neutrality [13, 17]. This contains neutrality and objectiveness in terms of normative and thus cultural aspects. TA focuses the assessment of new technologies (e.g., robots) in terms of arising chances and risks for the environment and the consequences for the society [5, 11]. Moreover, TA is established to provide orientation. So, as it is pointed out in this paper, it is not even an option but a necessity to focus on normative aspects driving and controlling TA including techniques themselves, the goals to protect and many further dimensions [13]. Thus, this paper shows a concept that is based on the idea of the socio-ecological approach of TA including the insight that problems are always defined socially and culturally [5]. The cultural background consisting of various basic assumptions and resulting in-/formal norms determines how people look at things such as new technologies [5, 6, 13]. This is caused in the reason that the assessment takes place based on different cognitive models that are implicit and often unconscious.

In this context the *metaphorical culturalistic approach (MCA)* of TA is presented containing a new way of looking at TA enhancing former approaches by using the metaphor of cultural glasses pointing out the direct interdependence of culture in terms of our assessment (Fig. 9). The *enhanced metaphorical culturalistic approach* presented in this paper states that each cultural orientation can be seen as *coloured glasses* which determine our view of things we look at in an incremental way. Hereby the importance of cultural aspects is pointed out since people are always determined directly in an incremental way by their cultural orientation like wearing cultural glasses. This requires dropping out holding on the idea of neutrality of TA and substitute that view with a new metaphorical culturalistic way of looking at TA.

In this context reflexive normativity comes into play including different methods and approaches such as e.g., the introduction of codes of conduct or rules of practice [13]. Moreover, creating standards aims to establish and to operationalize reflexivity in TA practice, too. Beside that the involvement of supervisors who critically question the assumptions of the project can be useful for the sake of more reflexivity. Reflexivity along the entire process can thus be implemented [13]. By noting normatively relevant questions and reflecting them critically research diaries as well as reflexive journals document the research process [13]. Furthermore, an important aspect is to increase the heterogeneity of TA for the sake of a more holistic view. Therefore, the early inclusion of further actors from the field of governance, natural, social, and human sciences is important to address different social norms and values in a very early stage [13, 18]. Then, normative ideals that drive scientific research can be focused, analysed, and disclosed. Consequently, the reflection of socio-ethical aspects as well as the plurality of opinions during the TA process is supported [2, 13, 16, 18]. A very useful method to implement such a reflexive normativity is the LOTA method [6].

The most important point of today´s TA is focusing on cultural and in consequence normative aspects, instead of neglecting them because normative aspects can be found in the whole TA process [13]. Then TA becomes not normative neutral (that is impossible since humans are part of it) but aware of its implicit normativity. That offers the chance, to change implicit to explicit reflexive normativity and to enhance the transparency in terms of TA [13].

In this context the *metaphorical culturalistic approach* (MCA) presented in this paper offers an incremental and crucial new insight presented as metaphor. The most important insight is understanding that each person has implicit cultural assumptions understood as cultural glasses with different color which determine how we look at things as well how we assess things in detail e.g., new technologies.

Notice

The paper was presented at MOTSP 2021 – 12th International Conference Management of Technology – Step to Sustainable Production, which took place in Poreč/Porenzo, Istria (Croatia), on September 8–10, 2021. The paper will not be published anywhere else.

7 REFERENCES

[1] Neugebauer, R. (2018). *Digitalisierung: Schlüsseltechnologien für Wirtschaft & Gesellschaft*, Springer. https://doi.org/10.1007/978-3-662-55890-4

[2] Grunwald, A. (2019). *Technology assessment in practice and theory*, Routledge. https://doi.org/10.4324/9780429442643

[3] Kornwachs, K. (2018). Technikfolgenabschätzung als technikwissenschaftliche Disziplin? Methodenmix und Modellbildung. *TATuP - Zeitschrift für Technikfolgenabschätzung in Theorie und Praxis, 27*(1), 46-51. https://doi.org/10.14512/tatup.27.1.46

[4] Decker, M. (2007). Praxis und Theorie der Technikfolgenabschätzung. Erste Überlegungen zu einer methodischen Rekonstruktion. *TATuP, 16*(1), 25-34. https://doi.org/10.14512/tatup.16.1.25

[5] Renn, O. (2013). *Auf dem Weg zu einer sozialökologischen Fundierung der Technikfolgenabschätzung*. Simonis, G. (edt.), *Konzepte und Verfahren der Technikfolgenabschätzung*, 21-30. https://doi.org/10.1007/978-3-658-02035-4_2

[6] Mader, C., Hilty, L., Som, C., & Wäger, P. (2019). Transparenz normativer Orientierungen in partizipativen TA-Projekten: ein Software-basierter Ansatz. *TATuP - Zeitschrift für Technikfolgenabschätzung in Theorie und Praxis, 28*(1), 58-64. https://doi.org/10.14512/tatup.28.1.58

[7] Weydner-Volkmann, S. (2019). Ethische TA als Kartographie situativer Wertungskonflikte. *TATuP - Zeitschrift für Technikfolgenabschätzung in Theorie und Praxis, 28*(1), 39-44. https://doi.org/10.14512/tatup.28.1.39

[8] Hennen, L. (2019). Max Weber revisited: Die Wertbeziehung(en) der Technikfolgenabschätzung. *TATuP - Zeitschrift für Technikfolgenabschätzung in Theorie und Praxis, 28*(1), 27-32. https://doi.org/10.14512/tatup.28.1.27

[9] Düwell, M., Hübenthal, C., & Werner, M. (2002). *Handbuch Ethik*, Stuttgart, 25-35. https://doi.org/10.1007/978-3-476-02713-9

[10] Schein, E. (2003). *Organisationskultur. The Ed Schein Corporate Culture Survival Guide*. Fatzer, G.

[11] Grunwald, A. (2007). Auf dem Weg zu einer Theorie der Technikfolgenabschätzung: der Einstieg. Einführung in den Schwerpunkt. *TATuP - Zeitschrift für Technikfolgenabschätzung in Theorie und Praxis, 16*(1), 4-17. https://doi.org/10.14512/tatup.16.1.4

[12] Hennen, L. (2019). Max Weber revisited: Die Wertbeziehung(en) der Technikfolgenabschätzung. *TATuP - Zeitschrift für Technikfolgenabschätzung in Theorie und Praxis, 28*(1), 27-32. https://doi.org/10.14512/tatup.28.1.27

[13] Kollek, R. (2019). Implizite Wertbezüge in der Technikfolgenabschätzung: Plädoyer für eine Praxis der reflexiven Normativität. *TATuP - Zeitschrift für Technikfolgenabschätzung in Theorie und Praxis, 28*(1), 15-20. https://doi.org/10.14512/tatup.28.1.15

[14] Torgersen, H. (2018). Die verborgene vierte Dimension. *TATuP - Zeitschrift für Technikfolgenabschätzung in Theorie und Praxis, 27*(1), 21-27. https://doi.org/10.14512/tatup.27.1.21

[15] Nierling, L. & Torgersen, H. (2019). Normativität in der Technikfolgenabschätzung. Einleitung in das TATuP-Thema. *TATuP - Zeitschrift für Technikfolgenabschätzung in Theorie und Praxis, 28*(1), 11-14. https://doi.org/10.14512/tatup.28.1.11

[16] Moser, E. (2018). Normative Leitbilder in der Technikfolgenabschätzung. *ITA-manu:script,* Nr.: ITA-18-02 http://epub.oeaw.ac.at/ita/ita-manuscript/ita_18_02.pdf

[17] Bimber, B. (1996). *The politics of expertise in congress. The rise and fall of the Office of Technology Assessment*, State University of New York Press.

[18] Sutcliffe, H. (2000). *A Report on Responsible Research and Innovation. MATTER and the European Commission,* https://ec.europa.eu/programmes/horizon2020/sites/default/files/rri-report-hilary-sutcliffe_en.pdf

Author's contacts:

Patricia Girrbach, Professor Doctor
FOM, Fachhochschule für Ökonomie and Management,
Rotebühlstraße 121, 70178 Stuttgart, Germany
Tel.: (+49) 800 1959595
p.girrbach@gmx.de

ISSN 1846-6168 (Print), ISSN 1848-5588 (Online)
https://doi.org/10.31803/tg-20210901142449

Subject review

A New "Intersection" Method for Multi-Objective Optimization in Material Selection

Maosheng Zheng*, Yi Wang, Haipeng Teng

Abstract: Till now the previous methods for multi-objective optimization adopt the "additive" algorithm for the normalized evaluation indexes, which has the inherent shortcoming of taking the form of "union" in the viewpoint of set theory. In fact, "simultaneous optimization of multiple indexes" should be more appropriate to take the form of "intersection" for the normalized evaluation indexes in the respects of set theory and "joint probability" in probability theory. In this paper, a new concept of favorable probability is proposed to reflect the favorable degree of the candidate material in the selection; All material property indicators are divided into beneficial or unbeneficial types to the material selection; Each material property indicator correlates to a partial favorable probability quantitatively, and the total favorable probability of a candidate material is the product of all partial favorable probabilities in the viewpoints of "intersection" of set theory and "joint probability" in probability theory, which is the sole decisive index in the competitive selection process. Results of the application examples indicate the validity of the new method.

Keywords: favorable probability; material selection; multi-objective optimization; probability theory; quantitative assessment

1 INTRODUCTION

At present, there are more than 40,000 useful metal alloys and non-metal engineering materials in the world [1]. These large amounts of materials form a material library, which is available to designers and engineers together with many manufacturing processes and selection attributes (maybe conflicting with each other). Due to its complexity, it makes material selection an uneasy task.

Therefore, a commonly quantitative assessment for material selection is needed for the appropriate design and application of material in engineering.

It has been more than 40 years since the early work in material selection [2], a series of methods have been developed to analyze the big amount of data involved in material selection process so as to obtain a systematic result.

Farag et al proposed an integrated approach to the interrelated activities of product design, materials selection and cost estimation [1]. The wide range of engineering materials is first narrowed to a limited number of candidates using design limitations and performance requirements. Each of the candidate materials is used to develop an optimum design which is then used in cost estimation. An optimization technique, i.e. benefit - cost analysis, is used to select the optimum design - material combination for the initial screening of materials. This method is lacking of quantitative comparison of other attributes, such as difficulty of manufacturing and processing technique, environment, etc. In his book [2], the performance index method is introduced, which is an alternative form of the weighted property method in aiming to overcome the drawback of combining unlike units together in the original weighted property method by introducing scaling factors [2]. However, in the scaling process the scaled value is proportional to normal material property value for the beneficial material property index, but the scaled value of the unbeneficial material property index is in reverse ratio to the normal material property value, which obviously sets the beneficial property index and unbeneficial property index in a nonequivalent or unconformable manner [2].

Ashby developed material selection charts for a wide range of materials. Two performance indices are shown in a chart [3]. A wide range of physical properties of materials (i.e. electronic conductivity, elastic modules, etc.) are correlated to the interstice parameters (i.e. density, heat capacity, etc.) empirically in the chart, which is suitable for the initial screening of materials due to the lacking of effective comparison of other indexes, such as processing technique and difficulty of manufacturing, environment, etc.

Analytical Hierarchy Process (AHP) was developed by Saaty, AHP is a theory of measurement through pairwise comparisons that relies on the judgments of experts to give priority scales. Through these scales the intangibles are measured relatively. The comparison is made using an absolute judgment scale, which indicates the degree to which one element dominates another element in terms of a given attribute. Obviously, in order to conduct the scaling process, the denominator is subjectively selected, which affects the value of each decision matrix element and determines the final result of the comparison. Different scaling algorithm, the such as vector normalization, linear scale method, extreme value processing method, and standard deviation normalization method, etc., will lead to different result [4].

Vlšekriterijumsko KOmpromisno Rangiranje (VIKOR) method was developed by Opricovic, which determines the compromise ranking-list, the compromise solution, and the weight stability intervals for preference stability of the compromise solution obtained with the initial (given) weights. The multi-criteria ranking index Q is proposed on basis of the particular measure of "closeness" to the "virtual ideal solution", besides an artificial weighting factor ν is introduced in evaluation procedure of VIKOR value Q. [5].

Technique of ranking Preferences by Similarity to the Ideal Solution (TOPSIS) was proposed by Hwang and Yoon originally in 1981, and further developed by Chen and Hwang in 1992 [6]. The TOPSIS method introduces two "virtual ideal points", i.e., the so called a "positive ideal solution" and a "negative ideal solution". TOPSIS method determines the best alternative by minimizing the distance to the ideal positive solution and maximizing the distance to the

negative ideal solution. In addition, a scaled decision matrix and Euclidean distances are utilized in TOPSIS to measure the alternatives with their positive ideal solution and negative ideal solution. The preference order of alternatives is obtained through ranking the Euclidean distances. The validity of the "virtual ideal points" and the denominator in the scaling is not clarified.

Multi-Objective Optimization on the basis of Ratio Analysis (MOORA) for discrete alternatives was developed by Brauers, el al. [7]. This method depends on a ratio system in which each response of an alternative on an objective is divided by a denominator, which is representative for all alternatives concerning that objective. Furthermore, these responses are added in case of maximization and subtracted in case of minimization for the optimization. Obviously, in MOORA, the reasonability of the selection for the denominator to each response of an alternative and the algorithm of "added in case of maximization and subtracted in case of minimization" in final optimization procedure are unclear.

From above discussion, it can be seen that since the introduction of artificial factors or subjective denominator in the scaling process for the normalization of decision matrix in some methods, the relevant algorithms could not be seen as complete quantitative ones, which are at most semi - quantitative approaches in some sense. Besides, the treatment for beneficial property index and unbeneficial property index is not equivalent and conformable in some approaches. On the other hand, the previously proposed methods for multi-objective optimization adopt especially "additive" algorithm after parameterization and scaling of the evaluation indexes to get the final unified indicator for the candidate. From the perspective of "simultaneous optimization of multiple indexes", which is equivalent to taking the form of "union" in set theory [8], it has the shortcomings inherently. In fact, from the points of view of set theory and probability theory, "simultaneous optimization of multiple indexes" should be more appropriate to take the form of "intersection" and "joint probability" for the evaluation indexes [8]. Therefore, comprehensive study in materials selection is still needed so as to develop a quantitative and overall approach.

The motivation of this research for the multi-objective optimization is from the "simultaneous optimization of multiple indexes" that corresponds to "intersection" method in the point of view of set theory. In this paper, a new "intersection" method for multi-objective optimization in material selection is developed on basis of set theory and probability theory. A new concept of favorable probability is introduced, and the total favorable probability of a candidate material is the product of the partial favorable probabilities of all possible material property indicators for the candidate material in the point of view of probability theory, which is the overall consideration of all possible material property indicators. The total favorable probability of a candidate material is the decisive index for the material to get victory in the selection process.

2 A NEW "INTERSECTION" METHOD FOR MULTI-OBJECTIVE OPTIMIZATION ON BASIS OF PROBABILITY THEORY

2.1 Concept of Favorable Probability for Material Selection

Usually, a material exhibits many features in different sides; each material property indicator could reflect one aspect of the material characteristics in some sense. Some material property indicators might be beneficial to the material selection, but other property indicators are unbeneficial (cost) to the material selection. In fact, an actual material is the integral body of both beneficial and unbeneficial indicators to the material selection and utilization. It is not possible for a material to have only full beneficial or unbeneficial property indicators to the material selection and utilization. So, an overall consideration for material selection is needed in the viewpoint of impersonal analysis, which makes the material selection a systemic and comprehensive task. Therefore, both beneficial and unbeneficial (cost) indicators should be dealt with properly, so as to propose an integral and overall consideration to the material selection quantitatively.

Take the design and manufacture of a flight as an example, the strength and ductility of a candidate material are the beneficial indicators for the material selection, while the specific gravity (density) is unbeneficial indicator to the material selection. The beneficial indicators have the characteristics of the higher the better, while the unbeneficial (cost) indicators have the characteristics of the lower the better to the material selection.

Therefore, all the material property indicators are divided into two types, i.e., beneficial or unbeneficial (cost) types to the material selection naturally.

As a quantitative assessment to the term "the higher the better" and "the lower the better" for a material property indicator, a new concept of "favorable probability" can be introduced; the favorable degree of the material property indicator in the material selection competition can be characterized quantitatively by the favorable probability comparatively.

2.2 Quantitative Assessments of Favorable Probability and Multi-Objective Optimization in Material Selection

From the principle of simplicity, it assumes that the favorable probability of a material property indicator with the character of "the higher the better" (beneficial indicator) in the material selection process is positively correlative to this material property indicator linearly, i.e.

$$\begin{aligned} &P_{ij} \propto X_{ij}, \\ &P_{ij} = \alpha_j X_{ij}, \end{aligned} \quad i = 1, 2, ..., n;\ j=1, 2, ..., m. \tag{1}$$

In Eq. (1), X_{ij} represents the j^{th} material property indicator of the i^{th} candidate material; P_{ij} is the partial favorable probability of the beneficial material property indicator X_{ij}; n is the total number of candidate materials in the material group involved; m is the total number of material

property indicators of each candidate material in the group; α_j is the normalized factor of the j^{th} material property indicator.

Furthermore, according to the general principle of probability theory [8], the summation of each P_{ij} for the index i in j^{th} material factor is normalized and equal to 1, i.e., $\sum_{i=1}^{n} P_{ij} = 1$, thus, it obtains naturally

$$\sum_{i=1}^{n} \alpha_j X_{ij} = \sum_{i=1}^{n} P_{ij} = 1,\ \alpha_j = \frac{1}{n\overline{X}_j}. \quad (2)$$

$\overline{X}_j$ is the average value of the j^{th} material property indicator in the material group involved.

Equivalently and conformably, the partial favorable probability of the unbeneficial (cost) material property indicator X_{ij} is negatively correlative to its material property indicator linearly, i.e.

$$\begin{aligned} &P_{ij} \propto (X_{j\max} + X_{j\min} - X_{ij}), \\ &P_{ij} = \beta_j (X_{j\max} + X_{j\min} - X_{ij}), \end{aligned} \quad i = 1, 2, ..., n;\ j = 1, 2, ..., m. \quad (3)$$

In Eq. (3), $X_{j\max}$ and $X_{j\min}$ represent the maximum and minimum values of the material property indicator X_j in the material group, respectively; β_j is the normalized factor of the j^{th} material property indicator.

Correspondingly, by using the normalization principle of probability theory generally [8], it obtains ordinarily

$$\beta_j = \frac{1}{\left[n(X_{j\max} + X_{j\min}) - n\overline{X}_j \right]}. \quad (4)$$

Furthermore, according to basic probability theory [8], the total / comprehensive favorable probability of the i^{th} candidate material to be selected is the product of its partial favorable probability of each material property indicator P_{ij}, i.e., "joint probability" or "intersection" in set theory,

$$P_i = P_{i1} \cdot P_{i2} \cdots P_{im} = \prod_{j=1}^{m} P_{ij}\ . \quad (5)$$

Finally, the total favorable probability of a candidate material is the sole decisive index and dominator for the material selection comparatively; the ranking of the candidate materials can be conducted according to their values of total favorable probability, which decides the winner of the material selection.

The main characteristics of our new "intersection" method for multi-objective optimization in material selection on basis of probability theory is that the treatment for both beneficial property index and unbeneficial property index is equivalent and conformable without any artificial factors or subjective scaling factor.

By far, the concept of favorable probability and its quantitative assessment as well as the new multi-objective optimization method for material selections are developed.

3 APPLICATION OF THE NEW METHOD OF MULTI-OBJECTIVE OPTIMIZATION IN MATERIAL SELECTION

3.1 Material Selection for a Rectangular Beam

Md Abdul Maleque once proposed a problem of material selection for a rectangular beam with a length of 0.5 m and width of 50 mm, which is subjected to a concentrated load of 10 kN acting in the middle of the beam [9]. There were four candidate materials for this rectangular beam design. Table 1 cites the material property indicators of the candidate materials in the rectangular beam design. The candidate materials shown in Tab. 1 could form a candidate material group for the selection process.

Table 1 Properties of candidate materials for the rectangular beam design [9]

Materials	Elastic modulus E (GPa)	Specific gravity d (g/cm^3)	Relative cost C
Steel AISI 1020	207	7.86	1
Steel AISI 4140	210	7.86	1.5
Al 6061 T6	70	2.7	6
GFC	25	2.11	9

The material property indicator E has the characteristic of the higher the better for this usage, so the factor E is the beneficial property indicator to the material selection; while the specific gravity d and the relative cost index C are the unbeneficial material property indicators to the material selection, which have the characteristic of the lower the better. So, the assessment for partial favorable probabilities of beneficial or unbeneficial type material property indictors can be conducted according to Eqs. (1) and (2), or Eqs. (3) and (4), separately.

Tab. 2 shows the results of partial favorable probability P_{ij} and the total favorable probabilities P_i assessed for each material property indicators for the four candidate materials.

Table 2 Partial and total favorable probabilities of the candidate materials for the rectangular beam design

Materials	P_{ij} for E	P_{ij} for d	P_{ij} for C	$P_i \times 100$	Rank
Steel AISI 1020	0.4043	0.1090	0.4000	1.7634	1
Steel AISI 4140	0.4102	0.1090	0.3778	1.6896	2
Al 6061 T6	0.1367	0.3757	0.1778	0.9132	3
GFC	0.0488	0.4062	0.0444	0.0882	4

It can be seen from the last column of Tab. 2 that the comparative result clearly shows the maximum value of total favorable probabilities P_i being steel AISI 1020, so the optimal selection for the material of rectangular beam design is steel AISI 1020, which agrees with the common knowledge.

3.2 Material Selection for Automotive Piston Design

Md Abdul Maleque also raised a problem of material selection for automotive piston design [9]. Tab. 3 cites the material property indicators of the seven candidate materials in the automotive piston design [9]. The material property indicators 3, 4, 6 and 7 are beneficial indicators, and the

material property indicators 1, 2, 5 and 8 are unbeneficial indicators for the material selection, respectively. In addition, the material property indicators 6 and 7 are both the material strength indicators with the similar meaning and function, therefore the material factor 6 is taken into consideration here only.

Tab. 4 presents the results of partial favorable probabilities and the total favorable probability assessed for each material property indicator of the seven candidate materials.

Table 3 Material properties indicators of the candidate materials in automotive piston design [9]

Material	Material property factor							
	1	2	3	4	5	6	7	8
	Friction coefficient	Wear rate ($\times10^{-6}$mm^3/N/m)	Thermal capacity (kJ/kg·K)	Thermal conductivity (W/m·K)	Specific gravity (Mg/m^3)	Yield strength (MPa)	Tensile strength (MPa)	Relative cost
GCI	0.41	2.36	0.46	80	7.2	460	455	1
Ti-alloy	0.34	246.3	0.58	17.58	4.42	700	1014	20
Ni-alloy	0.39	5.32	0.41	12.6	8.4	851	1100	17
Al-alloy	0.36	2.89	0.714	190	2.73	480	510	10
AMC 1	0.35	3.25	0.98	155	2.7	276	310	2.8
AMC 2	0.44	2.91	0.92	180	2.8	425	485	2.6
TMC	0.31	8.19	0.51	17.85	4.68	700	1029	20.5

Table 4 Partial and total favorable probabilities of the candidate materials for automotive piston design

Material	P_{ij} for 1	P_{ij} for 2	P_{ij} for 3	P_{ij} for 4	P_{ij} for 5	P_{ij} for 6	P_{ij} for 8	$P_i\times10^6$	Rank
GCI	0.1283	0.1676	0.1006	0.1225	0.0871	0.1182	0.2676	0.7301	4
Ti-alloy	0.1547	0.0016	0.1268	0.0269	0.1492	0.1799	0.0196	0.0004	7
Ni-alloy	0.1358	0.1656	0.0896	0.0193	0.0603	0.2187	0.0587	0.0301	5
Al-alloy	0.1472	0.1673	0.1561	0.2930	0.1870	0.1233	0.1501	3.8700	3
AMC 1	0.1509	0.1670	0.2143	0.2374	0.1876	0.0709	0.2441	4.1642	2
AMC 2	0.1170	0.1672	0.2011	0.2756	0.1854	0.1092	0.2467	5.4180	1
TMC	0.1660	0.1637	0.1115	0.0273	0.1434	0.1799	0.0131	0.0279	6

Tab. 4 shows that the ranking order of this material selection is AMC 2 > AMC 1 > Al – alloy > GCI > Ni – alloy > TMC > Ti – alloy. The best material selected from this procedure is AMC 2, which coincides with the result of the semi-quantitative method – the so-called digital logic method accidentally [9], while the selection process of the latter is quite complex. The subsequent ranking for other candidate materials is not exactly the same as the result of the digital logic method due to the utilization of weighting factors and performance index method in the latter [9].

3.3 Material Selection for Automotive Brake Pad Design

Md Abdul Maleque's next example is the design of an automotive brake pad [9]. Tab. 5 cites the material property indicators of the four candidate materials in the automotive brake pad design [9]. The yield strength Y is the beneficial material property indicator, while specific gravity d and relative cost C are unbeneficial (cost) type material property indicators in the material selection, individually.

Tab. 6 presents the results of partial favorable probabilities and the total favorable probability assessed for each material property indicator of the four candidate materials.

Table 5 Candidate materials for automotive brake pad design [9]

Materials	Specific gravity d (g/cm^3)	Yield strength Y (MPa)	Relative cost C
Alumina whiskers	3.8	300,000	3.5
CFRP	2.0	544	4.5
4340 Steel	7.8	296	1
Al-alloy	4.5	420	6

Table 6 Partial and total favorable probabilities of the candidate materials for automotive brake pad design

Materials	P_{ij} for d	P_{ij} for Y	P_{ij} for C	$Pi\times100$	Rank
Alumina whiskers	0.2844	0.9958	0.2692	7.6238	1
CFRP	0.3697	0.0018	0.1923	0.0128	2
4340 Steel	0.0948	0.0010	0.4615	0.0043	3
Al-alloy	0.2512	0.0014	0.0769	0.0027	4

From Tab. 6, it can be seen that Alumina whiskers is the appropriate material comparatively in the competition, which agrees with the elementary knowledge.

3.4 Material Selection of Polymeric Nano-Composite Material for Automotive Bumper Beam

Hasanzadeh et al studied the material selection of polymeric nano-composite material for automotive bumper beam by using multi-criteria decision making methods [10], including AHP - TOPSIS, AHP - MOORA, Entropy - TOPSIS and Entropy - MOORA. Three PA-6 based nano - composites with the codes of M-1, M-2 and M-3 and three PC based nano - composites with the codes of M-4, M-5 and M-6 were employed [10], the material property indicators including difficulty in manufacture and relative cost are cited in Tab. 7.

In Tab. 7, the relative cost of the raw materials was evaluated in range from highest value of 6 to the lowest value of 1, and the difficulty of the manufacturing process was evaluated in range from most difficult with value of 6 to the easiest with value of 1 as well. The material property indicators of tensile strength and impact strength have the feature of beneficial indicators, and the material indicators of the relative cost and difficulty in manufacture have the nature of unbeneficial indicators for the material selection, individually.

Table 7 Material property indicators of the 6 nano-composites

Alternative	Tensile strength (MPa)	Impact strength (MPa)	Relative cost	Difficulty in manufacture
M-1	25	113.07	4	1
M-2	37.55	103.54	5	2
M-3	34.79	96.51	6	3
M-4	135.38	224.58	1	4
M-5	141.71	154.06	2	5
M-6	141.92	133.53	3	6

The ranking of the evaluation results by using the new quantitative method is shown in the second column of Tab. 8. In addition, the ranking of alternatives which were assessed by using other four methods are cited in subsequent columns of Tab. 8 [10] as well.

Table 8 Ranking of the alternatives corresponding to the 5 assessments

Alternative	New method	AHP-TOPSIS	AHP-MOORA	Entropy-TOPSIS	Entropy-MOORA
M-1	4	4	4	4	4
M-2	5	5	5	5	5
M-3	6	6	6	6	6
M-4	1	1	1	1	1
M-5	2	2	2	2	2
M-6	3	3	3	3	3

The assessment results for the ranking of the alternatives in Tab. 8 show a consistent consequence accidentally, but the new method is rather simple without any subjective factor.

4 APPLICATION IN MULTI-OBJECTIVE TEST DESIGN

The new multi-objective optimization method for material selection proposed in section 2 could be extended in application of multi-objective orthogonal test design and uniform experimental design due to the similarity of the problems.

In general, the multi-objective orthogonal test design is conducted by the so called "comprehensive balance method" or "comprehensive scoring method" [11], or "grey relational analysis" [12], signal to noise ratio analysis [13], which involve personal factors and are not full quantitative, but an empirical ones instead.

Cheng et al proposed a multi-objective robust optimization method based on parameter design using inner - outer array, analysis of signal to noise ratio (SNR) and the technique for order preference by similarity to ideal solution (TOPSIS) [14]. Then formulation of the process parameter schemes is conducted on basis of uniform experimental design and stepwise regression analysis [14], which is rather complex in addition to the common problems of TOPSIS and SNR.

In this section, the new method developed in the section 2 is utilized to study the multi-objective orthogonal test design and uniform experimental design so as to extend its application in optimal design quantitatively.

4.1 Multi-Objective Optimization Design on Extrusion Process for Joint Bearing

Xin et al. conducted the multi-objective optimization on extrusion process for joint bearing by FEM software [11], it involves three input variables and four levels, i.e., extrusion groove depth and width of bearing outer ring and the feeding amount of mold as the input variables. The bearing crevice Δt, the maximum extrusion force F_{max} and the maximum contact pressure P_{max} of liner are taken as the indicators of the multi targets by using orthogonal test design with the help of comprehensive balance analysis method [11].

The indicators Δt, F_{max} and P_{max} are all unbeneficial indicators to the technique optimization, therefore, Eqs. (3) and (4) are employed to perform the assessment for their partial favorable probability.

Tab. 9 cites the results of the orthogonal test design optimization on extrusion process for joint bearing [11]. Tab. 10 presents the results of the test and the partial favorable probabilities as well as total favorable probabilities for bearing tightness, the maximum extrusion force and the maximum contact pressure of liner.

In Tab. 10, the test 4 exhibits the maximum of the total favorable probability P_i, it could be chosen as one of the optimal combination in the multi-objective orthogonal test design directly.

Table 9 Factors and levels of the orthogonal test design optimization on extrusion process for joint bearing [11]

Levels	Process factors		
	Groove depth d (mm)	Groove width h (mm)	Feeding amount of mold l (mm)
1	0.28	7.6	6.35
2	0.42	9.1	6.40
3	0.56	10.6	6.45
4	0.70	12.1	6.50

Table 10 Results of orthogonal test design for optimization on extrusion process for joint bearing [11]

Test No.	Process factors			Objective indicator			Partial favorable probability			Total favorable probability	
	d	h	l	Δt (mm)	F_{max} (kN)	P_{max} (MPa)	P_{ij} for Δt	P_{ij} for F_{max}	P_{ij} for P_{max}	$P_i \times 10^4$	Rank
1	1	1	1	0.019	108	481	0.0774	0.0550	0.0630	2.6818	9
2	1	2	2	0.011	107	506	0.0925	0.0558	0.0598	3.0850	5
3	1	3	3	0.014	97	465	0.0868	0.0629	0.0650	3.5483	3
4	1	4	4	0.014	87	431	0.0868	0.0701	0.0693	4.2109	1
5	2	1	2	0.021	113	537	0.0736	0.0515	0.0560	2.1192	10
6	2	2	1	0.018	100	469	0.0792	0.0608	0.0645	3.1051	4
7	2	3	4	0.021	98	500	0.0736	0.0622	0.0606	2.7732	8
8	2	4	3	0.026	76	376	0.0642	0.0779	0.0762	3.8066	2
9	3	1	3	0.03	120	599	0.0566	0.0465	0.0482	1.2671	15
10	3	2	4	0.025	114	600	0.0660	0.0508	0.0481	1.6105	12
11	3	3	1	0.03	83	415	0.0566	0.0729	0.0713	2.9412	6
12	3	4	2	0.037	71	349	0.0434	0.0815	0.0795	2.8130	7
13	4	1	4	0.04	125	656	0.0378	0.0429	0.0410	0.6640	16

Table 10 Results of orthogonal test design for optimization on extrusion process for joint bearing [11] (continuation)

Test No.	Process factors			Objective indicator			Partial favorable probability			Total favorable probability	
	d	h	l	Δt (mm)	F_{max} (kN)	P_{max} (MPa)	P_{ij} for Δt	P_{ij} for F_{max}	P_{ij} for P_{max}	$P_i \times 10^4$	Rank
14	4	2	3	0.034	110	582	0.0491	0.0536	0.0503	1.3232	14
15	4	3	2	0.041	87	465	0.0358	0.0701	0.0650	1.6321	11
16	4	4	1	0.049	65	327	0.0208	0.0858	0.0823	1.4653	13

Furthermore, Tab. 11 presents the results of range analysis of the total favorable probabilities for the orthogonal test design of optimization on extrusion process for joint bearing.

Table 11 Results of range analysis of the total favorable probabilities for the orthogonal test design of optimization on extrusion process for joint bearing

Level	d	h	l
1	3.3815	1.6830	2.5483
2	2.9510	2.2810	2.4123
3	2.1580	2.7237	2.4863
4	1.2712	3.0740	2.3147
Range	2.1103	1.3909	0.2337
Order	1	2	3

From range analysis of the data in Tab. 11, it shows that the order of the input variables for impact decreasing is from d, h to l. The optimal combination is $d_1h_4l_1$, which coincides with the result of the complex comprehensive balance method in the multi-objective orthogonal test design accidentally [11]. The FEM simulation test indicates that the corresponding bearing crevice Δt is 0.04 mm, the maximum extrusion force F_{max} and the maximum contact pressure P_{max} of liner decreased by 47.3% and 65.6% as compared to the previous condition before optimization [11], respectively, which reflects the validity of the optimization.

4.2 Multi-objective robust optimization of injection molding process parameters based on TOPSIS and uniform experimental design

Cheng et al dealt with the problems of multi-objective robust optimization of injection molding process parameters based on technique for order preference by similarity to ideal solution (TOPSIS) and uniform experimental design for mobile phone panel [14]. The volume shrink rate ϕ_{shr} (%), sink index I_{sink} (%), buckling deformation W (mm) were taken as the objective indicators, and the input variables include melt temperature, injection time and packing pressure while keeping injection pressure of 100 MPa, packing time of 3 s and the cooling time of 5 s, then the uniform experimental design was conducted.

Tab. 12 multi-objective robust optimization of injection molding process parameters based on TOPSIS and uniform experimental design [14].

Table 12 Uniform experimental design $U_{10}(5^3)$ for the optimization [14]

Factors	Levels				
	1	2	3	4	5
Melt temperature X_1 (°C)	265	270	275	280	285
Injection time X_2 (s)	0.50	0.55	0.60	0.65	0.70
Packing pressure X_3 (MPa)	70	75	80	85	90

Since the volume shrink rate ϕ_{shr}, sink index I_{sink}, buckling deformation W are unbeneficial indicators to the technique optimization, therefore, Eqs. (3) and (4) are employed to perform the assessment for their partial favorable probability.

Tab. 13 presents the results of the partial and total favorable probabilities for the volume shrink rate ϕ_{shr}, sink index I_{sink}, and buckling deformation W in the uniform experimental design.

In Tab. 13, the test 2 exhibits the maximum of the total favorable probability P_i, while the total favorable probability of test 1 is very close to the maximum total favorable probability Pi, so they could be chosen as one of the optimal combination in the multi-objective uniform experimental design directly.

Table 13 Results of the multi-objective robust optimization of injection molding process parameters based on TOPSIS and uniform experimental design [14]

No	X_1	X_2	X_3	ϕ_{shr} (%)	I_{sink} (%)	W (mm)	P_{ij} for ϕ	P_{ij} for I	P_{ij} for W	$P_i \times 10^3$	Rank
1	2	5	5	6.037	3.230	0.4048	0.1084	0.1140	0.1074	1.3279	2
2	4	1	5	6.200	3.393	0.3735	0.1059	0.1097	0.1144	1.3297	1
3	5	2	2	6.895	4.057	0.4306	0.0953	0.0920	0.1016	0.8917	6
4	4	5	1	6.937	4.090	0.4695	0.0947	0.0911	0.0929	0.8020	7
5	3	3	3	6.587	3.744	0.4314	0.1000	0.1003	0.1015	1.0182	5
6	2	1	1	7.114	4.286	0.5103	0.0921	0.0860	0.0838	0.6622	9
7	5	4	4	6.299	3.471	0.3815	0.1045	0.1076	0.1126	1.2658	3
8	3	3	3	6.587	3.744	0.4314	0.1000	0.1003	0.1016	1.0184	5
9	1	2	4	6.463	3.614	0.4406	0.1019	0.1038	0.0994	1.0516	4
10	1	4	2	6.777	3.938	0.5054	0.0971	0.0952	0.0849	0.7846	8

Cheng et al gave a test result of pack pressure P = 90 MPa, injection time = 0.7 s and melt temperature θ_{melt} = 275 °C, it is in fact with a compromised parameters of the tests 1 and 2 [14], which exhibits smaller volume shrink rate ϕ_{shr}, sink index I_{sink} and buckling deformation W and implies the validity of the novel assessment.

5 DISCUSSION

From above study, it can be seen that the new "intersection" method for multi-objective optimization in material selection on basis of set theory and probability theory treats both beneficial property index and unbeneficial property index equivalently and conformably, which is

impersonal without any personal or subjective scaling factor.

The evaluation results for material selection for a rectangular beam, automotive piston design, automotive brake pad and polymeric nano-composite material for automotive bumper beam, the multi-objective orthogonal test design and uniform experimental design are all acceptable and conform to known, which indicates the reasonability of the new "intersection" method.

The evaluation result of the new "intersection" method for multi-objective optimization in material selection is not needed to equal to other previous approaches exactly due to the utilization of personal coefficients or other subjective factors in the latter.

6 CONCLUSION

Through this study, a new "intersection" method for multi-objective optimization in material selection is developed based on the probability analysis for all possible material property indicators comprehensively. All the material property indicators are divided into beneficial type and unbeneficial (cost) type; each material property indicator contributes to its partial favorable probability in positively correlative or negatively correlative manner, individually. The total favorable probability of a candidate material is the product of its all possible partial favorable probabilities. The total favorable probability of a candidate material determines the final result of the material selection decisively and comprehensively.

Conflict Statement

There is no conflict of interest.

7 REFERENCES

[1] Farag, M. M. & EI-Magd, E. (1992). An integrated approach to product design, materials selection and cost estimation. *Materials & Design*, 13, 323-327. https://doi.org/10.1016/0261-3069(92)90001-X

[2] Farag, M. M. (2021). *Materials and Process Selection for Engineering Design*, 4th Edition, CRC Press, Taylor & Francis Group.

[3] Ashby, M. F. (1992). *Materials Selection in Mechanical Design*, Butterworth - Heinemann Ltd, Exeter.

[4] Jahan, A. & Edwards, K. L. (2015). A state – of – the - art survey on the influence of normalization techniques in ranking: Improving the materials selection process in engineering design. *Materials and Design*, 65, 335-342. https://doi.org/10.1016/j.matdes.2014.09.022

[5] Opricovic, S. & Tzeng, G. H. (2004). Compromise solution by MCDM methods: A comparative analysis of VIKOR and TOPSIS. *Europ. J. of Operational Research*, 156, 445-455. https://doi.org/10.1016/S0377-2217(03)00020-1

[6] Wang, P., Zhu, Z., & Wang, Y. (2016). A novel hybrid MCDM model combining the SAW, TOPSIS and GRA methods based on experimental design. *Information Sciences*, 345, 27-45. https://doi.org/10.1016/j.ins.2016.01.076

[7] Brauers, W. K. M. & Zavadskas, E. K. (2006). The MOORA method and its application to privatization in a transition economy. *Control and Cybernetics*, 35, 445-469.

[8] Brémaud, P. (2020). *Probability Theory and Stochastic Processes*, Universitext Series, Springer, Cham. 7-11. https://doi.org/10.1007/978-3-030-40183-2

[9] Maleque, M. A. & Salit, M. S. (2013). *Materials Selection and Design, Springer*, Heidelberg, 81-83. https://doi.org/10.1007/978-981-4560-38-2

[10] Hasanzadeh, R., Azdast, T., Eungkee Lee, R., & Afsari Ghazi, A. (2017). Experimental polymeric nano-composite material for automotive bumper beam by using multi-criteria decision making methods. *Iranian J. of Materials Science & Eng., 14*(3), 1-10.

[11] Xin, L., Wang, X., & Huang, X. (2019). Multi-objective optimization design on extrusion process for joint bearing. *Forging & Stamping Technology, 44*(7), 79-85.

[12] Obara, C., Mwema, F. M., Keraita, J. N., Shagwira, H., & Obiko, J. O. (2021). A Multi - response optimization of the multi-directional forging process for aluminum 7075 alloy using grey-based Taguchi method. *SN Applied Science*, 3(596), 1-20. https://doi.org/10.1007/s42452-021-04527-2

[13] Teruo, M. (2011). *Taguchi Methods, Benefits, impacts, Mathematics, Statistics, and Applications*, ASME Press, New York, 7-204.

[14] Cheng, J., Tan, J., & Yu, J. (2011). Multi-objective robust optimization of injection molding process parameters based on TOPSIS. *Journal of Mechanical Engineering*, 47, 27-32. https://doi.org/10.3901/JME.2011.06.027

Authors' contacts:

Maosheng Zheng
(Corresponding author)
School of Chemical Engineering, Northwest University,
No. 229, Taibai North Road, Xi'an, 710069, Shaanxi Province, China
E-mail: mszhengok@aliyun.com

Yi Wang
School of Chemical Engineering, Northwest University,
No. 229, Taibai North Road, Xi'an, 710069, Shaanxi Province, China

Haipeng Teng
School of Chemical Engineering, Northwest University,
No. 229, Taibai North Road, Xi'an, 710069, Shaanxi Province, China

ISSN 1846-6168 (Print), ISSN 1848-5588 (Online)
https://doi.org/10.31803/tg-20190308110830

Professional paper

Overview of Environmental Problems Caused by Logistics Transportation: Example of European Union Countries

Abdullah Emre Keleş*, Gökhan Güngör

Abstract: Logistic transportation works is considered the main pollutant for the environment, with over 25 per cent CO_2 emissions in the EU. This situation has raised concerns for the EU and governments to find solutions and impose regulations to diminish the environmental impact. The purpose of this paper is to investigate two questions regarding environmental issues connected to transportation; "What are the recent trends for establishing sustainable logistics for different transportation methods?" "Which alternatives can be incentivized to decrease the environmental impact of transportation activities?" These projects among the most noteworthy environmental benefits, which are also the case studies of this research are The Viking Concept, The WestMed Bridge, Scandinavian Shuttle and Baxter Inland Sea Transport. The result highlighted in this research is that shifting transportation modes has been successfully implemented, with considerable positive outcomes in terms of environment impact, cost and lead times in several European Union funded projects.

Keywords: construction works; environmental solutions; green logistics; logistic solutions; sustainable logistics

1 INTRODUCTION

Logistic systems have been improved for over the years to become faster and more efficient with a focus on lower costs and lead times. As this approach make businesses profitable, the environmental issues are often neglected in the firm's strategy. EU governments are concentrating efforts to reduce the negative environmental impact by imposing new regulations for pollutants. As such, the transportation sector has being identified as a major source of pollutants, with 32% of total energy consumption in the EU, resulting in 44% of CO_2 emissions from fossil fuels [1]. Other issues such as the degradation of the ozone layer, noise, vibrations and atmosphere pollution are also side effects of the transportation sector [2].

Because of increased number of motor vehicles and migrations, the use of motor fuels has risen. Transport is the sector in that the most of fossil [3]. This situation threatens future generations because of damage to the environment.

Construction work to use hundreds of different materials, bringing them to the site, such as storage, transport needs. Since the environmental damage is high and the impact is large, the sector must be controlled.

In the logistics literature, sustainability and environmental issues are topics of increased interest, as more firms engage in such efforts to reduce risks and improve the competitive of the firm day by day [4-7]. It has usually claimed by these researchers that sustainability efforts in general lead to improvements in economic performance.

The purpose of this paper is to investigate environmental issues connected to logistics of sustainable transportation. The focus will be on analysing different transportation methods, considering cost, time, efficiency and environmental impact specifically. Considering the fact that the main purpose of all companies is profit, the importance of this issue is better known. Especially in recent years, it has become one of the more important issues for construction companies. Legal regulations are also forcing companies in this regard in EU.

2 MATERIAL AND METHOD

In this paper, several academic papers were reviewed to establish the theoretical background, further complemented with four case studies. In searching relevant literature, keywords such environmental responsible logistics, sustainable logistics, sustainable transportation, green logistics were used. The cases studies helped to identify recent trends in the market towards establishing sustainable transport logistics. Moreover, the benefits and challenges of each trend supported the understanding of optimal transportations methods with the lowest environmental impact, as well as other benefits.

The paper is limited to the European Union level, considering only external logistics transportation. Another concept such as the level of centralization was recognized as a factor for sustainable logistics and briefly mentioned.

2.1 Environmental Impact of Logistics Activities

Transportation in logistic activities is considered the main pollutant for the environment. Regulations require companies to adopt environment friendly solutions for their activities and transportation methods. Therefore, the questions arise: What are the recent trends for establishing sustainable logistics for different transportation methods? Which alternatives can be incentivized to decrease the environmental impact of transportation activities?

As described above, effective distribution systems impacts air quality generates noise and contributes to the global warming. According to [8], the environmental impact by external transport causes emissions consisting mostly of nitrogen oxides, carbon monoxide, carbon dioxide, sulphur oxides, hydrocarbons and particles. These emissions are clearly presented to affect the environment locally, regionally

and globally, and the complexity of identifying and reducing them is related to the source of these emissions. Furthermore, the complexity increases with longer distances. Carbon dioxide is described to affect the environment in a longer time perspective in terms of global impact. Looking at different transportation systems (Fig. 1), it can be observed that the logistic activities involving transportation present a considerable threat to the environment [9].

Considering Cavagnaro and Cruiel [10] presenting three dimensions regarding sustainable development, Jonsson [8] uses a similar approach when identifying environmental impacts into three factors. These are financial, technological and social conditions where it is described that each company need to adapt their logistics solutions to these factors with the purpose to always consider the environmental impact.

Distribution systems has their own different level of environmental impact and important to consider both direct environmental impact as the indirect impact [8]. Distribution by railways constitutes of direct effects when diesel is used instead of electricity. However, using electricity will affect the environment indirect through its production. Looking at air transport the emissions of greenhouse gases is seen as the most serious problem. Finally, sea transport consumes relatively low energy per transported ton-kilometer where the emissions are small. Moreover, sea transport exploit less areas and gives therefore more advantage in an environmental perspective.

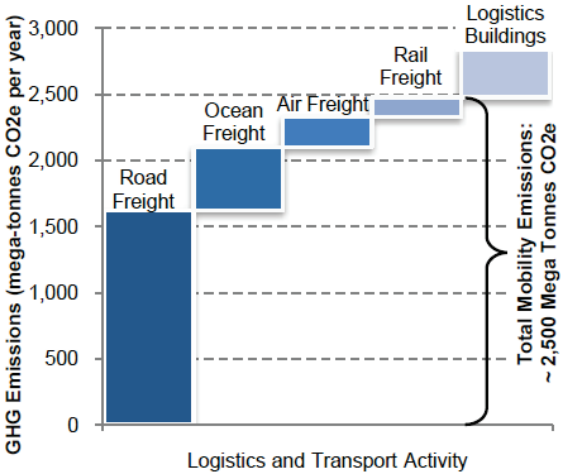


Figure 1 Logistics and Transport Activity [8]

According to Kohn and Bordin [11], the performance of logistics can be measured and expressed in terms of service level and costs with the overall goal to achieve a service that is cost efficient. Namely, the traditional view of logistics is to maximize profit and minimizing lead-times and costs. This view of logistics has to change in order to become more environmentally friendly and sustainable. The total environmental impact of the logistics system should be added to the traditional view. In addition, to create a sustainable logistic system the different variables should be considered together [11].

There is an inherent conflict between the different variables that determine the logistics systems performance. Therefore, trade-offs are necessary to create the best overall performance and not focus on optimizing one variable at the expense of another. The goal should be to create a balance between the different variables without compromising the total overall performance [8].

To create a logistic system that balances the different variables requires management. One study carried out by Aronsson and Brodin [2] discusses how logistic systems environmental performance can be improved without compromising the performance in terms of service delivery and costs through centralization. They suggest that centralization creates opportunities that do not exist in a decentralized system such as consolidation and changes in transport modes. This is also supported by Kohn and Brodin [11] who state that centralization enable consolidation which has a positive impact on CO_2 emissions and costs. An increased level of centralization results in more transportations than a decentralized system. However, with appropriate strategic decisions, it is possible to improve the environmental performance of the logistic system without impairing the costs and service.

2.2 Policies of the European Union in Environmental Logistics

Logistics and transportation sector have direct interaction with sustainable environment issues in various aspects. Main problems arise from the mentioned sectors can be listed as follows:

- Fast increase in the number of vehicles
- Insufficient maintenance and misuse
- Old and inefficient vehicle stock
- Lack of air pollutant gas control
- Air pollution and vehicle traffic
- Urbanization around highways.

The first remarkable efforts towards establishing a common policy towards establishing a transportation mechanism within EU started at 1993 with the Maastricht Agreement. In this agreement, the basis of Trans-European Transport Networks (TEN-T) has been discussed, principles are set and legal documents have been prepared. The aim with this project was connecting the isolated regions to the rest of union and eliminating the bottlenecks which prevent the socio-economic de-fragmentation of the member countries [12].

Another purpose of the mentioned project was the integration of the logistics and transportation to the plans of sustainable development. Logistics is the leading sector within EU, in terms of influencing the sustainability policies. 25% of the CO_2 emission is caused just from the logistic related activities. Also, according to the data, 44% of the load transportation is done by highways, while the share of sea freight and rail freight are 39% and 10% respectively [13]. When the constant increase in the traffic population, deterioration in the services and air pollution are considered, it was evident that new precautions were necessary. The council defined restructuring of the motorways, development of railway network and prevention of the delays in airways

and more effective use of sea transportation as the new goals and started to incentivize projects which are serving for these purposes.

In the scope of TEN-T, 30 new projects have taken to evaluation which are believed to be finding solutions to the adaptation problems of recently joined countries to the European environmental standards and long term sustainable logistics. These projects included motorways, high speed trains, river transportation, and multi-mode methods. Apart all these different suggestions, the most remarkable one was the "Marco Polo Program" [14].

Marco Polo program is the most significant effort among the activities of European Union to solve the environmental problems related to logistics. It strives for offering alternatives to conventional motorway transportation with seaways, railways and inland waterways. Marco Polo as a whole is a funding program, which collects proposals for environment friendly transportation methods every year and provides funding for them. While the initial budget between 2003 and 2006 was 115 million Euros, it is increased up to 400 million later on, with the introduction of Marco Polo II program [12].

As stated before, the main purpose of the program is shifting the land transportation to the sea as much as possible. The researches show that especially the inland waterways are much safer and environment friendly compared to all other methods. Still, it is believed that inland waterways are not used as much as desired and Marco Polo wants to incentivize such methods with its funding. Under the scope of Marco Polo, there are several projects completed successfully. The term success here both satisfies the profitability and efficiency as well as environmental awareness. There are two examples of such projects you will find below with further details.

3 ANALYSIS: TRENDS FOR SUSTAINABLE LOGISTICS TRANSPORTATION

Reducing transport emissions is an important measure for companies in achieving greener logistics. As with the focus to stay competitive on the market with shorter lead times and cost benefits, it is argued that 'greening' efforts may affect logistic effectiveness and efficiency (Huaccho et al., 2013). Yet, leading companies are gradually implementing environmental principles in their supply chain, to the extent of a win-win situation, satisfying governmental policies but also focusing on the competitive advantage [15]. Looking on how companies have adapted new transportation solutions shows that environmental and cost requirements can be satisfied.

An effective trend is shifting the traditional road transportation to sea, inland or rail transportation. This solution has been adopted by several international shipping providers with great benefits. In the case of Baxter, switching transportation modes resulted into 40% cost savings and reduced environmental impact. The fuel consumption for barges was less with 20% per kg than the truck transportation, also having the advantages of reduced CO_2 emissions and eliminating trucks of the roads. This solution also increased certainty and faster delivery times, avoiding the high risk of road congestions [15]. Another approach of lowering transportation costs and environmental impact is the Viking Rail project, which focused on shifting 35 to 40% road transportation to rail by using an intermodal solution. This approach resulted in lowering CO_2 emissions by 63% as well as decreasing lead times for about 12 hours for some routes. As in the previous case, fewer trucks were used and this meant a reduction of -15 tonnes per year of CO_2, less fuel consumption by 3.5 million litres per year as well as considerable reduction of other pollutants e.g. nitrous oxide, sulphur oxide emissions. From a cost perspective, the benefits were less considerable with only 5% improvements [16].

3.1 The WestMed Bridge Project

Project Name: The WestMed Bridge
Funds: 4.5 Million Euros
Duration: April 2008 – March 2011
Contractor: Atlantica S.P.A di Navigazione, Italy

Figure 2 The WestMed Bridge Project

Shifting transportation modes proved also to be a wise choice in the case of The WestMed Bridge project as shown Fig. 2. It aimed at shifting the motorway transportation towards the sea, thus increase the environmental benefits and decrease the transportation costs. Using larger capacity barrels to carry the liquids, the total transportation capacity has been increased by 65%. The travel time of the products has become 1.3 times faster than before and the cost of transportation has been reduced by 40% compared to the former method. During the lifetime of the project, it is expected to shift 72585 trucks worth of load to be shifted to sea transport. While the fund given for WestMed Bridge was 4.5 million Euros, the environmental benefit is estimated to be around 66.5 million Euros. The numbers show that the project was successful from every aspect [12].

3.2 The Scandinavian Shuttle Project

Project Name: Scandinavian Shuttle
Funds: 2.5 Million Euros
Duration: June 2006 – May 2010
Contractor: UBQ AB of Malmö, Sweden
Total load shifted from motorway:
923 million tons/km
Estimated Environmental Benefit:
27,5 Million Euros

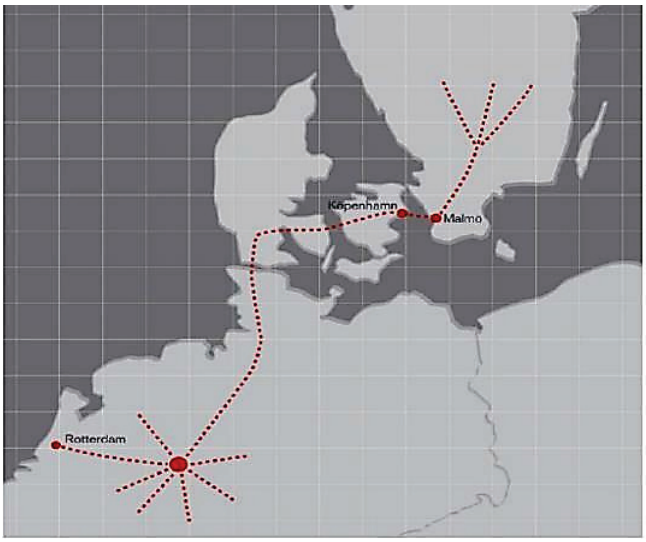


Figure 3 The Scandinavian Shuttle Project

A similar project, the Scandinavian Shuttle as shown Fig. 3, had also considerable benefits in terms of environmental and cost benefits. It aimed at building a long lasting railroad between central Europe and Scandinavia and shifting the traffic load caused from logistic activities between those two regions to railroad. The project started train expeditions between Sweden and Germany through Denmark. Since the contingencies are minimal in railroad transportation, the arrival times of the train to its destinations are planned with "just in time" principle. With the introduction of the railway, an alternative opportunity has been given which is also as flexible and reliable as the former methods. Overall, the Scandinavian Shuttle project managed to shift 923 million tons of loads from motorway and generated 27.5 million Euros worth of environmental benefit by the time of May 2010 [12].

The purpose of this paper was to investigate environmental issues connected to logistics of sustainable transport solutions. With theory that stresses the transportations' actual impact on the environment, combined with transportation solutions reviewed in four different cases, the conditions to begin with the analysis have now been established.

The number of pollution of 25% caused through logistics activities and where transportations represent 32% of total energy consumption, it has been clearly stated by Aronsson and Brodin [2] the serious and actual impact in the society. European Commission [12] presented common policies which become established in the early 90's and one thing to notice is the relation of the Maastricht Agreement with the socio-economic de-fragmentation. Equally with this agreement [17] emphasized almost two decades later the social dimension as an important part for sustainable society, together with the economic and the environmental perspective. Alänge et al. [18] identified sustainability as a starting principle for innovation and business development and this principle has actually been found in each of the four reviewed cases in this paper.

The Viking concept, the WestMed Bridge project, Scandinavian Shuttle project and Baxter inland sea transport, are all cases where environmental issues connected to sustainable transport solutions have been analysed and where recent trends have been reviewed. However, the positive outcome from these cases as acting beneficial to the environment additionally variables need to be considered, mentioned in theory as environmental management. As a matter of fact, Khon and Brodin, [11] emphasizes the importance of considering different variables together such as cost, time, efficiency. Based on that, several performance variables need to be considered when developing and evaluating new transportation solutions.

As has been mentioned actual cases bring up challenges and can be related to how to manage performance variables in order to reach the most beneficial outcome of new implemented sustainable transportation system. The analysis shows that sustainability is the driven action for new transportation solutions. However, what should be further analysed is if the success behind these presented cases is only connected to the indirect initiative by findings from the European Union.

4 CONCLUSION

In conclusion, it is evident that as a result of increasing globalization, the competitiveness of the market, intensity of environmental laws, customer expectations and social responsibilities of the companies are rising. Furthermore, considering the increasing attraction on the environmental issues today by individuals, organizations and companies from different industries makes it inevitable that some changes are going to take place in logistics industry to contribute the solution of this global problem. The numbers shown from various researches indicate that logistics industry has a major responsibility to carry out this change process, since it has a major role in the root of the problem. Recent trends in the approach of EU and the sector itself show that awareness is actually there, which is being the driving force to make both companies and authorities to step up their environmental efforts and revise their strategic plans accordingly.

On the legal side of the transformation of logistics into a more environmental friendly sector, biggest responsibility lies upon European Commission, as well as the particular authorities from the related countries. Looking at the recent efforts, it is observable that the commission is actively incentivizing the companies to take part in the resolution by shifting into greener logistic solutions. TEN-T program as a whole and Marco Polo program in particular are outstanding examples of collaborative handling of the common problem. Given that the mentioned cases in this paper are just a mare start and the programs themselves are looking for a 30-year

period, it is possible to make optimistic estimations about the future state of the industry.

On the sectorial side, it is encouraging to see that companies are taking the initiative to lead the change in accordance to the legal regulations. The decisions taken on the strategic level show their effects on the different faces of logistic activities throughout the supply chain, especially on the material transportation. The Viking concept, West-Med Bridge, Scandinavian Shuttle and Baxter inland sea transport can be regarded as major steps taken towards making a more green future for logistics and hopefully more projects will follow as it is seen that both environmental and monetary profits are remarkable. However, there are other concerns as well for logistic companies as mentioned such as cost, lead times, and flexibility and so on. Shifting their current practices with more environmental friendly ones may tackle them in those departments initially but, as new methods are established better over time, they would not be an issue any further.

To sum up, although there is still plenty of room for improvement, current efforts are giving the signal that the sector is on the right track. Emphasizing the importance of alternative transportation methods other than land freight (especially in-land water ways) seems to be the key factor for greener logistics in Europe. Maintaining the combination of incentives from the authorities and sense of responsibility from companies, will let the common understanding to be transferred to future generations for minimized environmental impact from logistics transport activities.

In all cases where environmental issues connected to sustainable transport solutions have been analysed, it is observed that the monetary value of the environmental benefits far outweighs the shifting costs. In the evidence of successful implementations in EU, the authors of this piece aspire to raise awareness locally on the same subject by arguing that it is possible to maintain the same productivity in alternative transportation while simultaneously earning major environmental benefits.

5 REFERENCES

[1] European Commission. (1992). Green paper on the impact of transportation on the environment. Available at: http://ec.europa.eu/greenpapers/pdf/transport_environment_gp_com_92_46.pdf.

[2] Aronsson, H. & Brodin, M. H. (2006). The environmental impact of changing logistics structures. *International Journal of Logistics Management, 17*(3), 394-415. https://doi.org/10.1108/09574090610717545

[3] Muhič, S., Čikić, A., Pištan, J., Stojkov, M. & Bošnjaković, M. (2018). Transport emissions and electric mobility in private transport in the Republic of Slovenia. *Tehnički glasnik, 12*(2), 98-103. https://doi.org/10.31803/tg-20180508162744

[4] Porter, M. E. & Van der Linde, C. (1995). Toward a new conception of the environment-competitiveness relationship. *Journal of Economic Perspectives, 9*(4), 7-118. https://doi.org/10.1257/jep.9.4.97

[5] Dey, A., LaGuardia, P., & Srinivasan, M. (2011). Building sustainability in logistics operations: a research agenda. *Management Research Review, 34*(11). 1237-1259. https://doi.org/10.1108/01409171111178774

[6] Rao, P. & Holt, D. (2005). Do green supply chains lead to competitiveness and economic performance? International *Journal of Operations & Production Management, 25*(9), 898-916. https://doi.org/10.1108/01443570510613956

[7] Pazirandeh, A. & Jafari, H. (2013). Making sense of green logistics. *International Journal of Productivity and Performance Management, 62*(8), 889-904. https://doi.org/10.1108/IJPPM-03-2013-0059

[8] Jonsson, P. J. (2008) *Logistics and supply chain management*. United Kingdom: McGraw-Hill Education.

[9] Doherty, S. & Hoyle, S. (Eds.) (2009). Supply Chain Decarbonization: The Role of Logistics and Transportation in Reducing Supply Chain Carbon Emission. *World Economic Forum*. http://www3.weforum.org/docs/WEF_LT_Supply ChainDecarbonization_Report_2009.pdf

[10] Cavagnaro, E. & Curiel, G. (2012). The three levels of sustainability. Sheffield: Greenleaf Publishing.

[11] Kohn, C. & Brodin, M. H. (2008). Centralised distribution systems and the environment: how increased transport work can decrease the environmental impact of logistics. *International Journal of Logistics: Research and Applications, 11*(3), 229-245. https://doi.org/10.1080/13675560701628919

[12] European Commission. (2010). Lightening The Load-Marco Polo Leads the Way. http://ec.europa.eu/transport/marcopolo/files/publi/docs/brochures/bestof_2009_en.pdf

[13] Commission of the European Communities. (2001). White Paper: European transport policy for 2010: time to decide. https://ec.europa.eu/transport/sites/default/files/themes/strategies/doc/2001_white_paper/lb_com_2001_0370_en.pdf

[14] European Commission. (2005). TEN-T Priority Axes and Projects 2005, http://ec.europa.eu/ten/transport/projects/doc/2005_ten_t_en.pdf.

[15] Pazirandeh, A. & Jafari, H. (2013). Making sense of green logistics. *International Journal of Productivity and Performance Management, 62*(8), 889-904. https://doi.org/10.1108/IJPPM-03-2013-0059

[16] European Logistics Association. (2010). Volvo Logistics European Rail Concept - Viking Rail. http://www.elabestlog.org/sites/default/files/cases/Viking%20Rail.pdf.

[17] Hawkins, C. V. & Wang, X. (2011). Sustainable development governance: Citizen Participation and support networks in local sustainability initiatives. *Public Works Management & Policy*, 1087724X11429045.

[18] Alänge, S. & Lundqvist, M. (2014). *Sustainable Business Development: Frameworks for Idea Evaluation and Cases of Realized Ideas*. Chalmers University Press, Gothenburg pp. 4-20.

Authors' contacts:

Abdullah Emre KELEŞ, Asst. Prof. Dr.
(Corresponding Author)
Adana Alparslan Türkeş Science and Technology University, Balcalı Mahallesi, Çatalan Caddesi No: 201/1 01250 Sarıçam/ADANA, Turkey
Tel: +90 (322) 455 00 00; Fax: +90 (322) 455 00 31
E-mail: aekeles@adanabtu.edu.tr

Gökhan GÜNGÖR, Postgraduate
Adana Alparslan Türkeş Science and Technology University, Balcalı Mahallesi, Çatalan Caddesi No: 201/1 01250 Sarıçam/ADANA, Turkey
Tel: +90 (535) 299 03 23; Fax: +90 (322) 455 00 31
E-mail: gokhangungor@hotmail.com

ISSN 1846-6168 (Print), ISSN 1848-5588 (Online)
https://doi.org/10.31803/tg-20210209155414

Professional paper

Preliminary Analysis of Load Input into the Accumulation Varaždin by Rain Overflow

Domagoj Nakić*, Tanja Trabe Baranašić, Dražen Vouk, Bojan Đurin

Abstract: The wastewater treatment plant Varaždin upgrade project envisages the reconstruction of the rain overflow directly upstream of the plant. Physicochemical parameters of water quality (Biological Oxygen Demand, Chemical Oxygen Demand, Total Nitrogen, Total Phosphorus, Suspended Solids) in sewage/drainage system and in the accumulation were analyzed. In accordance with expected values of concentrations in overflow and in the accumulation, an analysis of the water quality in the accumulation after mixing was performed with certain assumptions. The results show that the ecological condition of the accumulation generally remains unchanged, classified as good condition, except for Chemical oxygen demand which is a critical parameter. Paper refers to the frequency and duration of possible exceedances of the Chemical oxygen demand limits and gives critical analysis of the realistically expected impacts. A proposal for conducting more detailed analysis with a larger database and by modelling pollution discharge by a complex three-dimensional model is given.

Keywords: accumulation Varaždin; agglomeration Varaždin; rain overflow; regulation on water quality standard; wastewater treatment plant

1 INTRODUCTION

The quantity and quality of wastewater is determined by many factors. Not all humans or industries produce the same amount of waste. The design of the sewer system affects the wastewater composition significantly [1]. In combined systems a part of the total wastewater is discharged to local water bodies, often without any treatment. There is no doubt that the overflow structures in combined sewage systems are large and difficult to control sources of water pollution, especially in populated areas. If they want to be controlled, then it is very expensive, complex, and generally rarely sufficiently effective. Combined sewage is characterized by the presence of overflows, through which during rainy periods untreated wastewater together with stormwater flows from the sewer system to the receivers. Main role of overflows in mixed sewers is essentially economic. Discharging large amounts of stormwater directly into the receivers reduces the flow of water in the sewer downstream of the overflow structure and thus significantly reduces the cost of construction and operation of the sewer, but also the costs of wastewater treatment plants (WWTP). With the increase in water pollution because of accelerated urban development that generates large amounts of wastewater and polluted stormwater, such a concept of sewage/drainage is becoming less and less acceptable. Namely, overflow waters are a source of uncontrolled environmental pollution that can cause aesthetic pollution, increased health risk of disease for all direct or indirect users of the receiver (bacteriological pollution), environmental damage in the receiver and the associated environment (various pollutants contained in stormwater and municipal wastewater) and a reduction in dissolved oxygen levels that may adversely affect the living world of the receiver [2].

Various studies provide a wide range of pollution parameters in the stormwater runoff. The characteristics of stormwater runoff quality, hydrology, retention and other issues have all been examined in the literature, and it has been found that significant quantities of organics, nutrients, and heavy metals are present in stormwater runoff. It has long been recognized that the pollutant build-up and wash-off processes are influenced by rainfall and catchment characteristics [3]. However, the pollution parameters are many times higher in sanitary wastewater than in the inflow. The two definitions used worldwide are that one Population Equivalent (PE) produces about 150 l/d and 60 g/Biological Oxygen Demand (BOD) [4]. The actual contribution from a person living in a sewer catchment, so-called the Person Load, can vary considerably (Tab. 1).

Table 1 Variations in person load [1]

Parameter	Unit	Range
COD	g/cap·d	25-200
BOD	g/cap·d	15-80
TN	g/cap·d	2-15
TP	g/cap·d	1-3

*BOD – Bilogycal Oxygen Demand; COD – Chemical Oxygen Demand; TN – Total Nitrogen; TP – Total Phosphorus

The concentrations found in wastewater are a combination of pollutant load and the amount of water with which the pollutant is mixed. The daily or yearly polluting load may thus form a good basis for an evaluation of the composition of wastewater. The composition of municipal wastewater varies significantly from one location to another. On a given location the composition will vary with time. This is partly due to variations in the discharged amounts of substances. However, the main reasons are variations in water consumption in households and infiltration and exfiltration during transport in the sewage system. Stormwater will further dilute the wastewater as most stormwater components have lower concentrations compared to very diluted wastewater [4].

Tab. 2 provides a comparative presentation of the mean values of the concentrations of individual pollution parameters in the inflow and sanitary wastewater. Additionally, the limit values for wastewater emissions are stated, depending on the degree of treatment according to the Ordinance on Limit Values for Wastewater Emissions (NN 26/20) [5].

Table 2 Comparison of composition of raw municipal wastewater with minor contributions of industrial wastewater with pollution concentrations in stormwater from mixed residential-commercial urban watersheds (mean values) and wastewater emission limit values depending on the degree of treatment

Parameter	Unit	Raw municipal wastewater [4, 6-8]	Stormwater [3, 9-19]	Emission limit values depending on the degree of treatment [5]	
				II.	III.
BOD_5	mg/l	260.50	18.60	25	-
COD	mg/l	600.50	107.08	125	-
TN	mg/l	39.00	4.34	-	15 (10)**
TP	mg/l	7.75	1.09	-	2 (1)**
SS	mg/l	219.50	99.43	35	-

* SS – Suspended Solids
** WWTP capacity 10,000-100,000 PE (or over 100,000 PE)

Therefore, when discharging untreated mixed inflows into the environment, such water pollution is no longer acceptable to the public nor is it legally allowed, so it is necessary to control overflows, i.e. reduce or completely eliminate the negative impact on water resources, and the first step in this process is to analyse the impact of individual overflows on the water quality of the receiver. This paper provides an example of such preliminary analysis.

2 DESCRIPTION OF THE LOCATION AND TECHNICAL CHARACTERISTICS OF THE ANALYZED EXAMPLE

The wastewater and drainage system of the city of Varaždin is a combined system, which means that wastewater from households, industrial wastewater and rainwater is collected by a single collector network. The total length of the collectors is over 100 km. The total amount of mixed wastewater is discharged by the main collector profile DN3000, which is dimensioned for a flow of Q = 13.2 m³/s. Main rain overflow was built on the system, at the end of the main collector, and before mechanical and biological treatment within WWTP. As part of the actual project of the agglomeration Varaždin, it is planned to upgrade and reconstruct the WWTP, which will have a capacity of 127,000 PE with the 3rd stage of purification. The hydraulic capacity of the WWTP is calculated as Q_{max} = 716 l/s which will be transported by the inlet pumping station towards the mechanical pre-treatment. Wastewater inflow greater than 716 l/s will be directed via rain overflow into a retention basin with a volume of 2,500 m³. The retention basin should retain inflows up to $4Q_{dry}$ (1,440 l/s), which will prevent the overflow of wastewater of higher pollution into the recipient and ensure its additional protection. Wastewater inflows greater than 1.4 m³/s will activate rain overflow, which will gravitationally transport overflow waters to the right drainage channel of the hydro power plant (HPP) Čakovec accumulation. The maximum amount discharged by the gravitational part of overflow (overflow 1 in Fig. 1) is 7.36 m³/s (8.8-1.44 m³/s).

In the event of a flow of more than 8.8 m³/s, it will activate other part of the rain overflow (overflow 2 in Fig. 1) through which a maximum of 11.2 m³/s will be transported to pumping station with a useful volume of 400 m³. Pumping station will be equipped with vertical pumps (five pumps) that will transport overflow waters by the pressure pipeline through the right embankment into the accumulation of HPP Čakovec. In front of the rain overflow, automatic chain coarse grid of 5 cm openings, with a total capacity of 20 m³/s, will be installed in three parallel lines (6.67 m³/s each). Large automatic grates will remove large waste from wastewater, which will ensure the smooth operation of pumps in the pumping station for overflow waters and protect the recipient, i.e., the accumulation of HPP Čakovec.

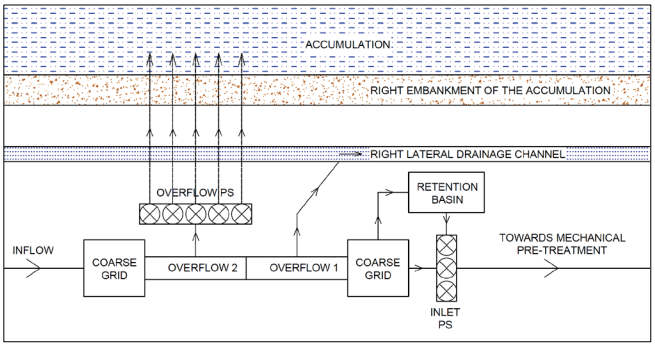


Figure 1 Schematic concept of the designed solution with rain overflow at the entrance to WWTP Varaždin

The receiver of the effluent from the WWTP Varaždin is the right drainage channel of the accumulation lake, which inflows downstream into the old Drava riverbed. It is envisaged that in the future project, the receiver of overflow quantities from the rain overflow in front of the WWTP will be the right drainage channel and the accumulation lake of HPP Čakovec (in case of heavier precipitation). Given that the accumulation has been identified as a sensitive part of this system, and the legislation generally restricts the discharge of wastewater into this type of water bodies, even if it is extremely rare and limited in time, as in this case, the impact of overflow on the quality of water in the accumulation will be analyzed below. Preliminary analysis of load input into the accumulation was performed in relation to the available input data. Due to the lack of continuous data during the calendar year, i.e. several years, data on minimum and maximum values of concentrations of water quality indicators of the influent and accumulation, and minimum and maximum values of flow through the accumulation were used. These data were used as input parameters for the calculation of concentrations after mixing of overflow waters and accumulation, and the determination of concentration limits of the ecological status of the water body for the basic physicochemical quality parameters.

3 ANALYSIS OF WASTEWATER AND ACCUMULATION OF HPP ČAKOVEC

3.1 Relevant Overflow Quantities and Accumulation Flow

The planned reconstruction of the rain overflow envisages the discharge into the recipient - the HPP Čakovec accumulation only in the case of precipitation resulting in higher total inflows (more than 8.8 m³/s). This roughly corresponds to precipitation of return period of 3 years, which was confirmed by using a hydraulic mathematical model of the sewage/drainage system (Fig. 2 - first graph).

The model was created using the EPANET software package, version 2.2.

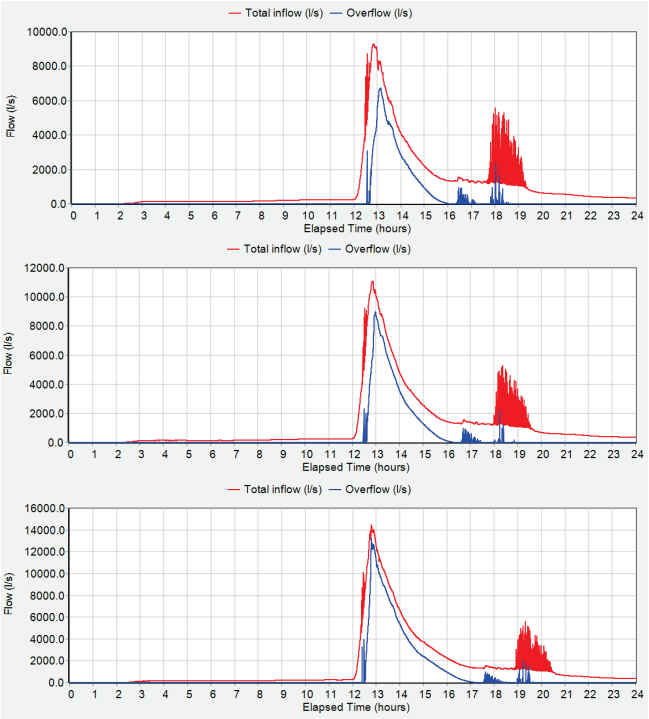


Figure 2 Results of the hydraulic model (EPANET, version 2.2) at the location of the analyzed rain overflow for the relevant precipitation of the RP 3, 5 and 10 years

As mentioned above, the maximum overflow expected into pumping station is projected at 11.2 m^3 /s. The project envisages a pumping station with 5 parallel pumps, each with a capacity of 2,240 l/s. This means that the maximum possible overflow into the accumulation is 11.2 m^3/s and this occurs when all 5 pumps are activated. However, from the graphs shown above, even in the case of precipitation for return period (RP) 10 years not all 5 pumps are activated, but only 3. Namely, with precipitation of 10 years RP total inflow at the location is approximately 14.2 m^3/s (Fig. 2 – third graph). This means that about 5.4 m^3/s of the total inflow remains for transfer into the accumulation (since 8.8 m^3/s goes downstream, towards the WWTP and the gravitational part of the overflow ending in the right drainage channel), which is easily covered by three pumps (Fig. 3 – Q3). Therefore, it can be concluded that the designed solution was made with an extremely high degree of safety and that the activation of all 5 pumps in the overflow pumping station is expected only in the event of precipitation of significantly higher RP (over 10 years). Fig. 3 shows the possible amounts of overflow water into the accumulation depending on the number of active pumps. For example, to activate all 5 pumps, the total inflow should be around 17.8 m^3/s (8.8 m^3/s going downstream and the amount of overflow 2 (from Fig. 1) greater than the capacity of 4 pumps, i.e. 8.96 m^3/s.

Another important amount for the subject analysis relates to the flow through the accumulation. Fig. 4 shows the measured data on accumulation flows for the period 2017-2019, where the values marked in red represent the absolute minimum, i.e., the maximum in the observed period.

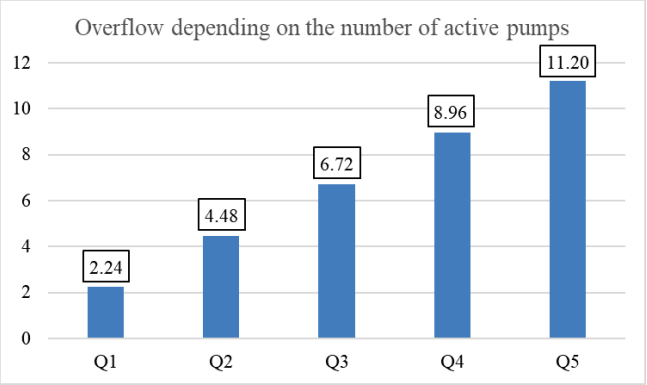


Figure 3 Possible variations of overflow into the accumulation

The presented results to be used in further analyses are summarized in Tab. 3. In the conducted analyses, the so-called constant accumulation volume is neglected, thus the results obtained will be on the safe side. Namely, the analyses below shows that the concentrations of individual pollution parameters in the accumulation are far below their values within the sewerage/drainage system, so mixing additional amounts of less polluted water would further contribute to dilution and reduction of total pollution concentrations.

Table 3 Recorded flows through the accumulation of HPP Čakovec for the period 2017-2019.

Flow	Min	Mean	Max
Q (m^3/s)	141	309	625

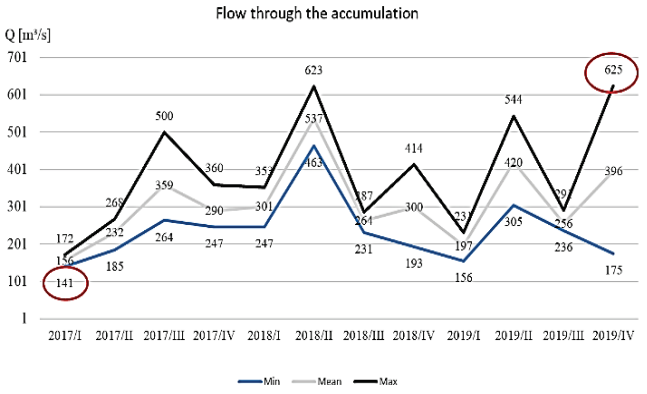


Figure 4 Flow changes through the accumulation for the period 2017-2019 with highlighted absolute minimum and maximum in the observed period

3.2 Water Quality in the HPP Čakovec Accumulation

Sampling of water quality in the HPP Čakovec accumulation is performed according to the Technical Observations Project, which is performed quarterly throughout the current year at specific, fixed control points, and for further analysis, four control points were taken as relevant for this analysis. The data taken for analysis at these points are the concentrations of water quality indicators [mg/l] BOD_5, COD, TN, TP, and SS in the period 2017 – 2019 (Tab. 4).

Table 4 Concentrations of water quality indicators in the accumulation for the period 2017-2019

Parameter	Unit	1	2	3	4	Min/Max	Mean
BOD_5 (min/max)	mg/l	0.50/ 2.00	0.50/ 2.70	0.60/ 1.70	0.50/ 2.00	0.50/ 2.70	1.15
COD (min/max)	mg/l	< 4.00/ 5.80	< 4.00/ < 4.00	< 4.00/ < 4.00	< 4.00/ < 4.00	< 4.00/ 5.80	4.83
TN (min/max)	mg/l	0.60/ 1.50	0.80/ 1.80	1.10/ 1.60	1.00/ 1.70	0.60/ 1.80	1.30
TP (min/max)	mg/l	0.01/ 0.17	0.02/ 0.11	0.02/ 0.10	0.02/ 0.13	0.01/ 0.17	0.07
SS (min/max)	mg/l	< 5.00/ 19.00	< 5.00/ 20.40	< 5.00/ 22.70	5.90/ 35.90	< 5.00/ 35.90	14.10

According to the Decree on Water Quality Standards (NN 96/19), the condition of a water body is assessed according to the value of the 50th percentile for rivers, transitional and coastal waters, i.e. the average annual concentration for lakes. These values are called the relevant values and are calculated on the basis of all measurement results, measured in different periods during the calendar year. Given the limited data available for this preliminary analysis, the mean values from the data presented above will be used for this classification, since these are estimated to be approximately relevant.

Table 5 Limit values of ecological status for basic physicochemical parameters for the water body of the HPP Čakovec accumulation

Panonska ecoregion		BOD_5 (mg/l)	COD (mg/l)	TN (mg/l)	TP (mg/l)
HR-R_5b	very good condition	1.50	2.50	1.20	0.05
	good condition	3.50	5.50	2.50	0.20

The analysis of water quality in the HPP Čakovec accumulation, based on the basic physicochemical quality parameters (Tab. 5), shows the characteristics of the category of good ecological condition.

3.3 Wastewater Quality

Sampling of wastewater, i.e. influent quality, the company Varkom d.d. performs on 24-hour composite samples that are tested and determined on the basis of the Ordinance on waste water emission limit values (NN 26/20). The summary results of these tests for the period 2017-2019 are shown in Tab. 6.

Table 6 Concentrations of wastewater quality indicators at the inlet of the WWTP for the period 2017-2019.

Parameter	Unit	Min	Mean	Max
BOD_5	mg/l	120.94	240.06	365.00
COD	mg/l	317.45	590.04	960.00
TN	mg/l	12.91	20.06	25.97
TP	mg/l	1.71	3.32	4.64
SS	mg/l	8.29	13.56	20.03

The analysis of wastewater quality in front of the WWTP (influent), shows that the concentrations are far above the emission limit values for pollutants in wastewater that are allowed to be discharged into the environment, and which are determined according to the Ordinance on wastewater emission limit values (NN 26/20, Annex I). The reason for this is that the analyzed wastewater is raw, and as mentioned before, result of 24-hour composite samples that were not diluted with large amounts of precipitation water and that were not taken instantly, during higher precipitation (and this is the time when the rain overflow is activated). Thus, taking these values for the calculation of the concentrations of the analyzed parameters in the accumulation after the inflow of overflow waters, obtained results are expected to be on the safe side, i.e. the conducted scenario assumes a hypothetical worst case.

4 ANALYSIS OF THE INFLUENCE OF OVERFLOW WATERS ON WATER QUALITY IN THE ACCUMULATION

Possible consequences of overflow water generally in relation to the parameters analyzed, are reflected in the following [2]:

- BOD_5 (COD) - reduction of the dissolved oxygen and mortality of wildlife
- TN and TP - eutrophication and algal blooms and deterioration of aesthetic values.

The calculation of the concentrations of physicochemical parameters in the accumulation after discharging the overflow waters was made within the following assumptions:

1) Instantaneous mixing of total quantities
2) The "constant" volume of the accumulation is neglected - only the flow through the accumulation is taken into account (this gives results on the safe side). Namely, there is always a certain amount of water in the accumulation, defined as a "constant" volume, while additional quantities flow through the accumulation and further through the engine room of the HPP. Since the concentrations of the observed pollution parameters are far lower in the accumulation compared to the wastewater, by mixing them the accumulation water actually lowers the concentrations of the mixture, and analysis that considers only the quantities flowing through the accumulation yields results on the safe side.

The calculation of concentrations in the accumulation after the discharge of overflow was calculated according to Eq. (1):

$$c_m = \frac{c_a \cdot Q_a + c_o \cdot Q_o}{Q_m}. \quad (1)$$

Where are: c_m - concentration of the observed parameter in the accumulation after discharge of overflow (mg/l); c_a - concentration of the observed parameter in the accumulation before discharge of overflow (mg/l); c_o - concentration of the observed parameter in the overflow (i.e., inflow) (mg/l); Q_a - flow through the accumulation (m^3/s); Q_o - overflow (m^3/s); Q_m - total flow as the sum of the flow through the accumulation and overflow (m^3/s).

Two extreme hypothetical cases were defined:

1. Best case scenario: $Q_{a,max}$ and $c_{a,min} + Q_{o,min}$ and $c_{o,min}$
2. Worst case scenario: $Q_{a,min}$ and $c_{a,max} + Q_{o,max}$ and $c_{o,max}$.

Although both scenarios defined are unlikely (it is to be expected that at higher overflows the flow through the accumulation will be higher because this is a moment of significant precipitation, and it is also to be expected that the concentrations in overflow waters due to dilution will be lower at higher overflows and vice versa), the actual range of concentrations of the analyzed parameters that can be expected in the accumulation, after overflow is discharged, is in the range between the values obtained for these two scenarios (Tab. 7). Still, expected concentrations in real conditions are much closer to lower presented values.

Table 7 Concentrations of water quality indicators in the accumulation after discharge of the overflow

Parameter	Unit	Best case scenario	Worst case scenario	Good condition limits
BOD_5	mg/l	0.93	29.36	3.50
COD	mg/l	2.20	76.02	5.50
TN	mg/l	0.64	3.58	2.50
TP	mg/l	0.02	0.50	0.20
SS	mg/l	4.91	34.73	-

Based on the results in Tab. 7, it is concluded that, if the overflow pumping station would be active all year round, the condition of the accumulation would meet the limits good condition in relation to the analyzed parameters for the best case scenario, while for the worst case scenario these values would be significantly exceeded for all analyzed parameters, especially organic load, i.e. oxygen demand in water (expressed as BOD_5 and COD).

With the same assumptions adopted previously, the so-called realistic scenario was defined so that mean values were taken for the relevant flow through the accumulation and for the concentrations of each pollution parameter in the accumulation. Overflow quantities are defined depending on the number of active pumps (Fig. 3) in the range of 2.24-11.20 m^3/s. Concentrations of pollution parameters in overflow are taken as minimum values based on wastewater sampling in front of the WWTP (Tab. 6) for the flow of the first pump (Q_1 = 2.24 m^3/s). Namely, in the conditions when the overflow pumping station is activated, a significant dilution is already present in the sewage/drainage system, and since the values shown in Tab. 6 are result of 24-hour composite samples, it is logical to choose minimum concentration values. For the values of concentrations in overflow resulting from pumps Q_2-Q_5, the average of mean values of individual pollution parameters in stormwater were chosen based on a literature review (Tab. 8).

Table 8 Literature range of pollution concentrations in stormwater from mixed residential-commercial urban watersheds [3, 9-19]

Parameter	Unit	Min	Mean	Max
BOD_5	mg/l	1.08	18.60	270.67
COD	mg/l	6.01	107.08	880,00
TN	mg/l	0.02	4.34	42.93
TP	mg/l	0.03	1.09	13.70
SS	mg/l	2.00	99.43	3,577.00

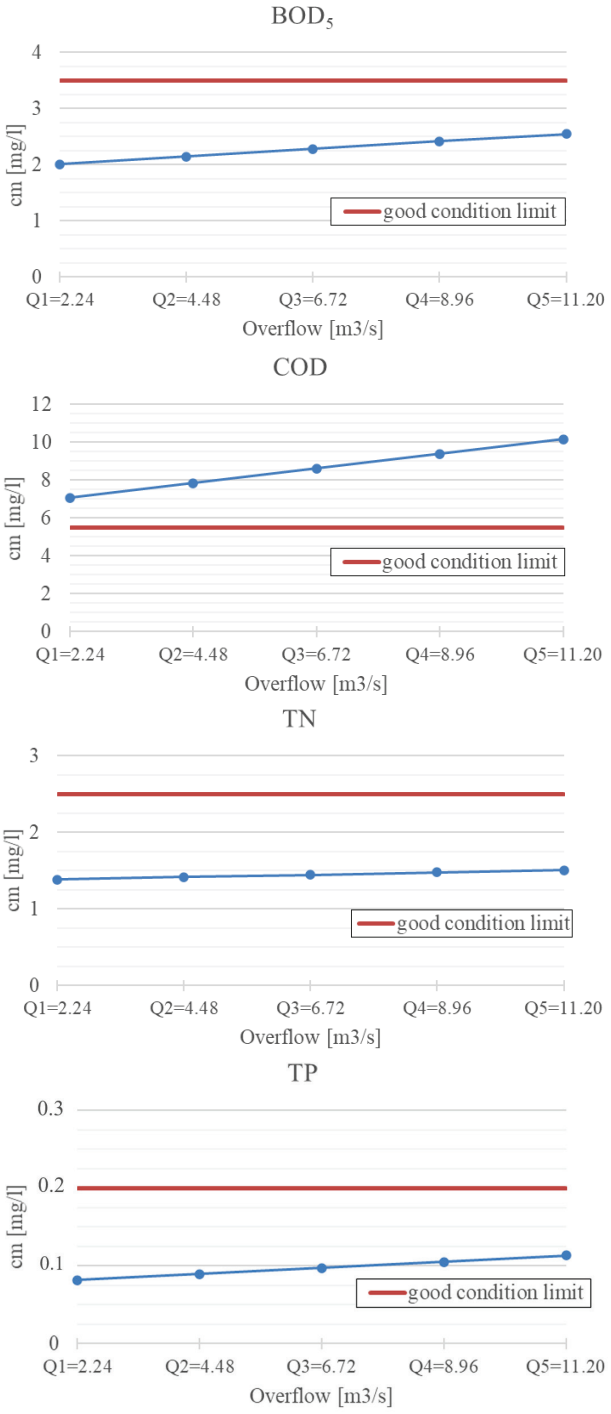


Figure 5 Concentrations of water quality indicators in the accumulation after discharge of overflow in relation to the amount of overflow water (number of active pumps) – realistic scenario

Results of this analysis are shown in the Fig. 5 from which exceeding the limit values of good condition of the water body of the accumulation (based on the analyzed parameters) occurs only regarding COD, while the other considered parameters are within limits regardless of the number of active pumps.

The presented results show that with a larger number of active pumps, the input of pollution into the accumulation also increases, although in these conditions the dilution is

significant. Again, the COD has been identified as a critical parameter, moreover, when operating more than one overflow pump, regardless of the concentration in the overflow waters of pump Q_1, it is not possible to meet the limits of good water body condition in a short term (Tab. 9). The reason for this is that the assumed concentration in the overflow waters Q_2-Q_5 (stormwater inflow) is already high enough to exceed the maximum allowable values. What needs to be emphasized is that these are extremely rare moments when more than one pump will be activated at all. Namely, with the precipitation of RP 3 years, only short-term activation of the first pump is expected, which based on the presented results may, depending on the actual concentration of COD in the sewage/drainage system, result in only short-term exceeding of good condition criteria. Based on the other analyzed parameters, good condition is always satisfied, regardless of the inflow and the number of active pumps. For the COD parameter, the risk of exceeding the good condition criteria increases with the increase in the number of active pumps and the amount of overflow water. Even for this criterion, these are extremely short-term effects (which occur only during the extreme precipitation) at a frequency level of an average of once in about 3 years or even less.

Table 9 Maximum allowable concentration of analysed pollution parameters in Q_1 overflow to maintain good condition of the accumulation

Parameter	Unit	Number of active pumps				
		1	2	3	4	5
BOD_5	mg/l	327.67	312.57	297.47	282.37	262.27
COD	mg/l	97.92	X	X	X	X
TN	mg/l	168.04	166.20	164.36	162.52	160.68
TP	mg/l	18.13	17.24	16.35	15.46	14.57

*X – not possible to meet the criterion of good condition

Table 10 Load input into the accumulation in the event of relevant precipitation of a RP of 3, 5 and 10 years

Parameter	Unit	RP 3 years	RP 5 years	RP 10 years
Overflow duration*	min	14.0	34.0	62.5
Average overflow*	l/s	321.5	1,148.6	2,601.9
Total overflow into the accumulation	m^3	270	2,343	9,757
BOD_5	kg/event	64.82	562.50	2,342.25
COD	kg/event	159.33	1,382.57	5,756.98
TN	kg/event	5.42	47.00	195.72
TP	kg/event	0.90	7.78	32.39
SS	kg/event	3.66	31.77	132.30

*Overflow above 8.8 m^3/s - since it is the part of the total overflow that goes into the accumulation (results of hydraulic model)

Concentrations of individual parameters in the accumulation are not the only parameter important for defining the impact of overflow quantities, and it is certainly necessary to have data on total amounts of pollution (mass inflow) that enter the accumulation during a certain period, for example at the annual level. It is necessary to know the data in the total time of overflow activation according to the accumulation in the observed period, which requires long series of historical data on precipitation. It is recommended to examine the above in the context of further analyzes. In relation to the available data set, Tab. 10 estimates the amounts of pollution that are introduced into the accumulation in the event of relevant precipitation of a RP of 3, 5 and 10 years and for mean concentrations of wastewater quality indicators at the inlet of the WWTP for the period 2017-2019 (Tab. 6). These are, especially in the case of organic load, significant absolute amounts, but it is still necessary to consider the frequency of occurrence of the analyzed events, i.e., on average once in 3, 5 or 10 years.

After conducting more comprehensive analysis using complete input parameters and preferably a 3D model of pollution discharge that would include all influential parameters, it is possible to apply additional measures to improve the condition of the accumulation, for example by introducing artificial aeration of the accumulation by surface aerators as aesthetically and environmentally acceptable solutions.

5 CONCLUSION

Paper presents preliminary analysis of load input by overflow in front of the WWTP Varaždin into HPP Čakovec accumulation. The impact on available oxygen (BOD_5 and COD parameters) and nutrient concentrations (TN and TP parameters) in the accumulation were analyzed. The results indicate that only in extremely short and rare periods deterioration in good condition of the accumulation could be expected. Such situations are expected at the level of an average of once in 3 years or less and in the maximum duration of extreme precipitation. In these extreme cases, the critical parameter is the content of dissolved oxygen in the accumulation expressed as COD.

With the aim to define the impact of load input in the accumulation using a comprehensive analysis the data on actual measured concentrations of pollution in the overflow in real time should be used, and with the rest of the data incorporated into complex 3D model which would include all influential parameters. In case of deterioration of the accumulation condition regarding dissolved oxygen levels, it is possible to consider additional measures to improve the water quality.

6 REFERENCES

[1] Henze, M., Harremoës, P., la Cour Jansen, J., & Arvin, E. (2002). *Wastewater Treatment: Biological and Chemical Processes*. 3rd ed, Springer-Verlag, Berlin. https://doi.org/10.1007/978-3-662-04806-1

[2] Margeta, J. (2011). Controlling negative effects of sewage water overflow. *Civil Engineer, 63*(7), 651-660.

[3] Li, D., Wan, J., Ma, Y., Wang, Y., Huang, M., & Chen, Y. (2015). Stormwater Runoff Pollutant Loading Distributions and Their Correlation with Rainfall and Catchment Characteristics in a Rapidly Industrialized City. *PLoS ONE* 10(3). https://doi.org/10.1371/journal.pone.0118776

[4] Henze, M., Van Loosdrecht, C. M., Ekama, G. A., & Brdjanovic, D. (2008). *Biological Wastewater Treatment – Principles, Modelling and Design*. IWA Publishing. https://doi.org/10.2166/9781780401867

[5] Ordinance on Limit Values for Wastewater Emissions (NN 26/20).

[6] Boutin, C. & Eme, C. (2016). Domestic Wastewater Characterization by Emission Source. *13eme congress*

spécialisé IWA on Small Water and wastewater Systems, Sep. 2016, Athens, Greece. 8 p.
[7] Ravndal, K. T., Opsahl, E., Bagi, A., & Kommedal, R. (2018). Wastewater characterisation by combining size fractionation, chemical composition and biodegradability. *Water Research,* 131, 151-160. https://doi.org/10.1016/j.watres.2017.12.034
[8] Von Sperling, M. (2007). *Wastewater Characteristics, Treatment and Disposal.* Biological Wastewater Treatment Series. Volume One. IWA Publishing.
[9] Bastian, R. K. (1997). Potential Impacts on Receiving Waters. Effects of Water Development and Management on Aquatic Ecosystems, Proceedings of an Engineering Foundation Conference, L. A. Roesner, ed. American Society of Civil Engineers, New York, NY.
[10] Brezonik, P. L. & Stadelmann, T. H. (2002). Analysis and predictive models of stormwater runoff volumes, loads, and pollutant concentrations from watersheds in the Twin Cities metropolitan area, Minnesota, USA. *Water Research*, 36, 1743-1757. https://doi.org/10.1016/S0043-1354(01)00375-X
[11] Caraco, D. & Schueler, T. (1999). Stormwater Strategies for Arid and Semi-Arid Watersheds. *Watershed Protection Techniques*, 3 (3), 695-706.
[12] Decree on Water Quality Standards (NN 96/19)
[13] EPA. (2015). Urban Storm Water Preliminary Data Summary. https://www.epa.gov/sites/production/files/2015-10/documents/usw_b.pdf
[14] Kabenge, I., Ouma, G., Aboagye, D., & Banadda, N. (2018). Performance of a constructed wetland as an upstream intervention for stormwater runoff quality management. *Environmental Science and Pollution Research*, 25, 36765-36774. https://doi.org/10.1007/s11356-018-3580-z
[15] Lee, J. H. & Bang, K. W. (2000). Characterization of urban storm water runoff. *Water Research*, 34 (6), 1773-1780. https://doi.org/10.1016/S0043-1354(99)00325-5
[16] Minnesota Pollution Control Agency (2020, November 10th). Minnesota Stormwater Manual - Guidance for meeting dissolved oxygen or oxygen demand TMDL MS4 permit requirements. Retrieved from https://stormwater.pca.state.mn.us/index.php?title=Guidance_for_meeting_dissolved_oxygen_or_oxygen_demand_TMDL_MS4_permit_requirements
[17] Ordinance on wastewater emission limit values (NN 26/20)
[18] Varkom d.d. (2019, February). Wastewater Laboratory Report for 2018., Varaždin. Retrieved from https://www.varkom.hr/stranica/kvaliteta-otpadnih-voda (in Croatian)
[19] Yufen, R., Xiaoke, W., Zhiyun, O., Hua, Z., Xiaonan, D., & Hong, M. (2008). Stormwater Runoff Quality from Different Surfaces in an Urban Catchment in Beijing, China. *Water Environment Research*, 80 (8), 719-724. https://doi.org/10.2175/106143008X276660

Authors' contacts:

Domagoj Nakić, PhD, Assistant Professor
(Corresponding author)
University North, Civil Engineering Department,
104. brigade 1, 42000 Varaždin, Croatia
Tel. +385911839023
E-mail: dnakic@unin.hr

Tanja Trabe Baranašić, mag. ing. aedif.
HEP proizvodnja d.o.o., Proizvodno područje HE Sjever,
Međimurska 26C, 42000 Varaždin
Tel. +38542408250
E-mail: tanja.trabebaranasic@hep.hr

Dražen Vouk, PhD, Associate Professor
University of Zagreb, Faculty of Civil Engineering,
Kačićeva 26, 10000 Zagreb, Croatia
Tel. +38514639213
E-mail: dvouk@grad.hr

Bojan Đurin, PhD, Associate Professor
University North, Civil Engineering Department,
104. brigade 1, 42000 Varaždin, Croatia
Tel. +385989749716
E-mail: bdjurin@unin.hr

ISSN 1846-6168 (Print), ISSN 1848-5588 (Online)
https://doi.org/10.31803/tg-20210513090824

Professional paper

Testing the Force Absorption of Composite Materials to Select the Best for Making a Helmet

Božo Bujanić, Matija Košak*

Abstract: The paper presents and describes the procedure of testing the materials that were available for the production of a multifunctional protective helmet. The procedure was carried out at the company Šestan-Busch d.o.o. as part of the EU project for the development and production of a multifunctional protective helmet. The test results showed that carbon fibers polymers as a composite material have the best impact absorption properties which was a key criterion for material selection. Other materials; glass fibers polymers, aramid fibers polymers and combinations in the test procedure showed worse results compared to the selected criterion.

Keywords: aramid fibers; carbon fibers; composite materials; glass fibers; impact absorption; multifunctional protective helmet

1 INTRODUCTION

The project of a multifunctional protective helmet (Fig. 1) was realized through the phases of design and development, procurement of specific equipment and realization i.e. serial production.

In the development and design phase, all the necessary input parameters were collected, i.e. data and information in order to be able to approach the development of a multifunctional safety helmet.

One of the requirements was that the helmet has the best possible protective properties against mechanical impacts and that it should be as light as possible, which required the selection of adequate materials for its production. The designers had at their disposal composite materials used to make protective helmets. Specifically, these were polymers with carbon fiber, glass fiber, aramid fiber, and a combination of aramid and carbon fiber [1].

These composite materials are characterized by high strength and low mass [2, 3]. Higher strength means that the material absorbs a large part of the impact force, which means that a smaller part of the impact force will be transferred to the head of the user using the helmet.

Figure 1 Multifunctional safety helmet [4]

2 TEST OF IMPACT RESISTANCE OF MATERIALS

The test was performed on a Hototech machine, shown in Fig. 2. The hototech machine is the machine with the special purpose of helmet impact testing but it can be used in different ways as well. The machine has the ability to release weights of a certain mass by free fall on the object under test, and is equipped with adequate software.

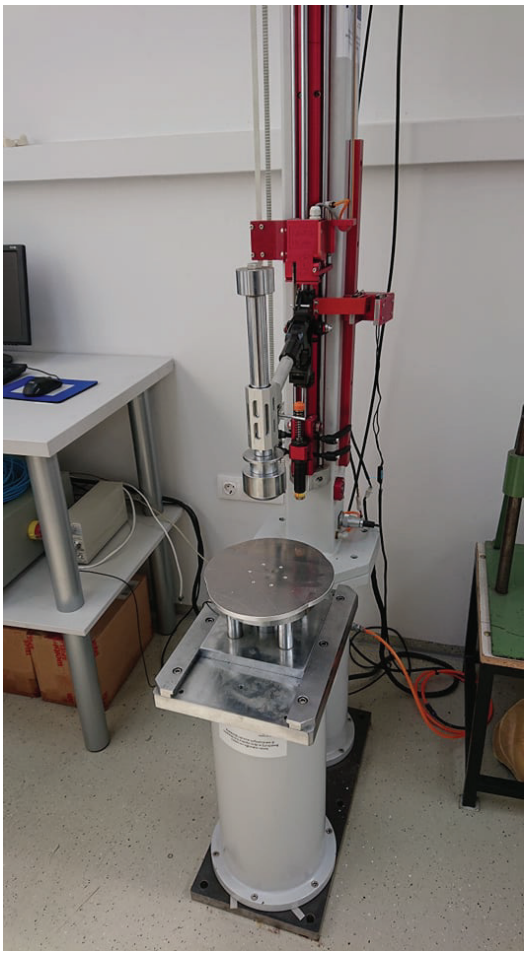


Figure 2 Shock absorbing device

2.1 Sample Preparation

Specimens prepared for the experiment were in the tile shape with dimensions 150 × 120 × 2 mm. Four types of specimens were prepared, tiles with carbon fibers reinforcement, aramid fibers, glass fibers and with the

combination carbon-aramid (2 layers of aramid fibers and 5 layers of carbon fibers). The tiles are shown in Fig. 3. From each of the listed materials, 6 tiles were made. Each tile consists of 7 layers of composite fibers. The tiles are made by manual lamination with epoxy resin matrix. By the procedure described in the book Comprehensive composite materials [5].

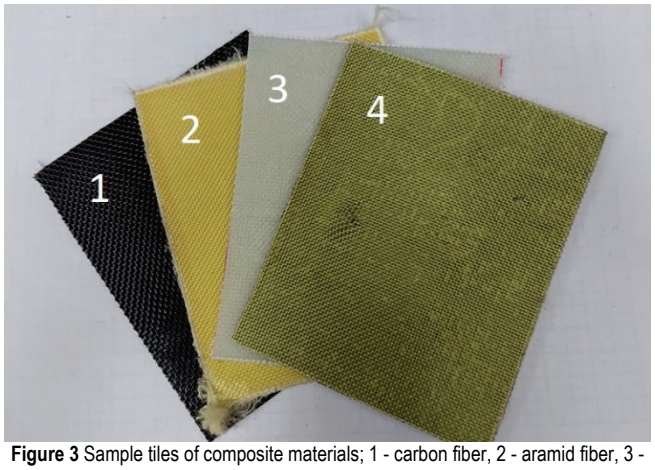


Figure 3 Sample tiles of composite materials; 1 - carbon fiber, 2 - aramid fiber, 3 - glass fiber, 4 - combination of aramid and carbon fiber

After preparing samples of composite materials, samples of PE foam were also prepared. The material of the foam is polyethylene because the pads in the interior of the protective helmet are made of the same material [6].

Foams measuring 125 × 155 × 10 mm and a foams measuring 125 × 155 × 20 mm were made for the two work cycles of the test.

2.2 Test Procedure

The test was conducted in three cycles, specifically;

- 1st test cycle of tiles without foam base,
- 2nd test cycle with a 10 mm thick foam base,
- 3rd test cycle with a 20 mm thick foam base.

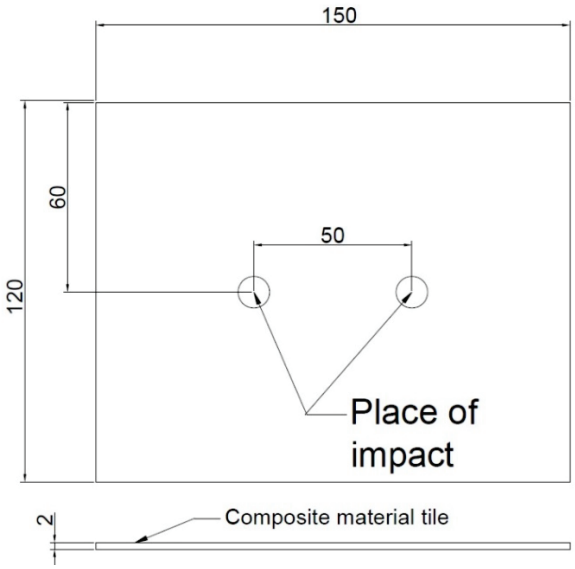


Figure 4 Drawing of the tile and the place of impact

The test cycles were carried out in such a way that a weight of 5 kg was released from the Hototech device from a height of one meter, and the residual force after impact on the sample was measured by means of a sensor. Two specimen of each material were tested in each of the cycles. In each cycle, the specimens were tested twice at precisely defined places (Fig. 4).

In addition to measuring the force on the device, the speed at certain heights of weights was also measured. After the test procedure the results could be compared and adequate conclusions could be drawn.

The first part of the tiles was tested without a foam which additionally absorbs the impact. In the second and third cycles, a foam 10 mm and 20 mm thick was placed under the tiles. After each impact, the force sensor measure the remaining amount of force that the material failed to absorb.

3 RESULTS AND DISCUSSION

3.1 Test Results

The results of the first cycle in which the tiles were tested without the foam are shown in Tab. 1. The values given in Tab. 1 show the force measured on the force sensor.

Table 1 Results for tiles without foam

Sample	Strike	Measured force (kN)			
		Glass fibers	Carbon fiber	Aramid fibers	A combination of carbon and aramid fibers
1st sample	I	21.63	21.02	21.59	21.29
	II	22.27	21.43	21.59	21.55
2nd sample	III	22.13	21.42	21.61	21.63
	IV	21.96	21.15	21.35	21.41
Arithmetic mean ($\bar{X}$)		21.99	21.25	21.53	21.47

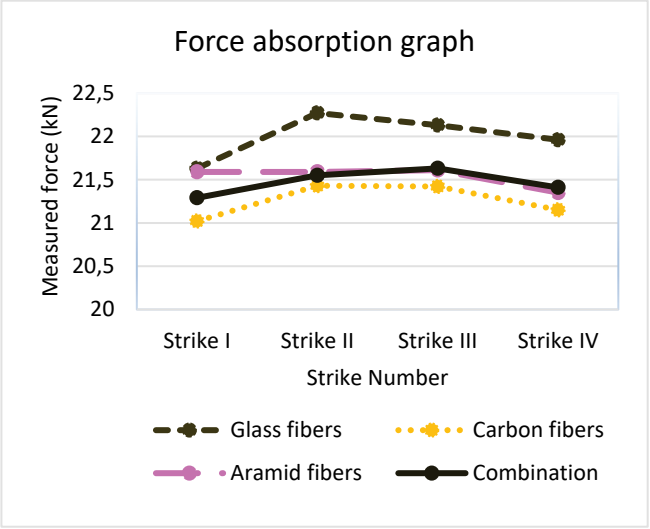


Figure 5 Presentation of the results of the first test cycle

In the test of composite materials on impact, in which there is no foam as an additional material for force absorption, forces from 21.25 kN to 22.47 kN were recorded, which can be seen in Fig. 5.

The best results in terms of absorption are observed on carbon fibers, followed by carbon fibers in combination with

aramid fibers, and aramid fibers while glass fibers showed the worst result and did not absorb force like other tested materials.

Tab. 2 shows the measured test values for the case when a 10 mm thick foam is placed under the composite tiles.

Table 2 Results for tiles with a 10 mm thick foam

Sample	The place of impact	Measured force (kN)			
		Glass fibers	Carbon fiber	Aramid fibers	A combination of carbon and aramid fibers
1st sample	I	10.71	7.67	12.5	9.56
	II	13.59	6.48	11.4	9.5
2nd sample	III	11.23	6.07	11.68	7.05
	IV	12.1	5.79	12.25	9.98
Arithmetic mean ($\bar{X}$)		11.91	6.50	11.96	9.02

In this test cycle, the largest differences between the results between different materials were observed, which is best seen in the deviation of the values of the forces obtained as a result (F_{min} = 5.5 kN, F_{max} = 13.5 kN). Fig. 6 shows the deviations of the results between the different materials for each individual test.

The best results were again achieved by carbon fibers, followed by a combination of aramid and carbon fibers, aramid fibers and glass fibers.

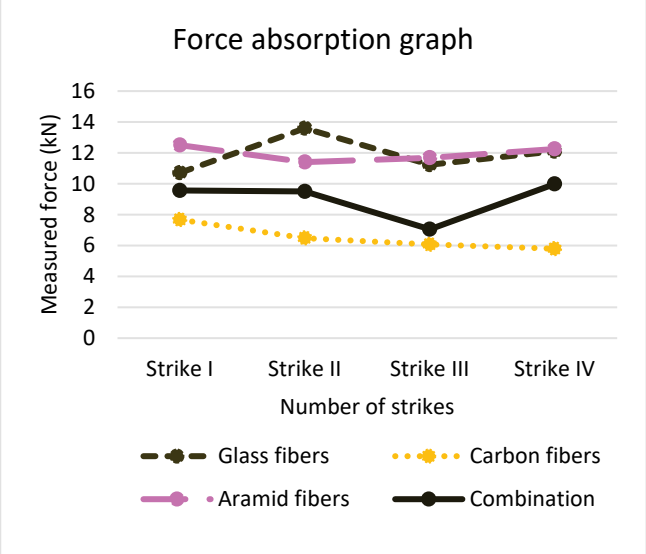


Figure 6 The results of the second test cycle

Table 3 Results for tiles with a 20 mm thick foam

Sample	The place of impact	Measured force (kN)			
		Glass fibers	Carbon fiber	Aramid fibers	A combination of carbon and aramid fibers
1st sample	I	2.86	2.82	3.1	2.76
	II	2.34	2.73	2.48	2.73
2nd sample	III	2.3	2.35	2.16	2.59
	IV	2.39	2.44	2.16	2.38
Arithmetic mean ($\bar{X}$)		2.47	2.58	2.47	2.61

The results of the last test cycle are shown in Tab. 3 and Fig. 7. The last cycle, in which there was a foam 20 mm thick under the tiles of composite materials, showed results that are almost the same for all materials and do not deviate between different materials. This occurs due to the thicker foam that absorbs most of the energy.

In Fig. 7, we see how similar the results are regardless of the type of material.

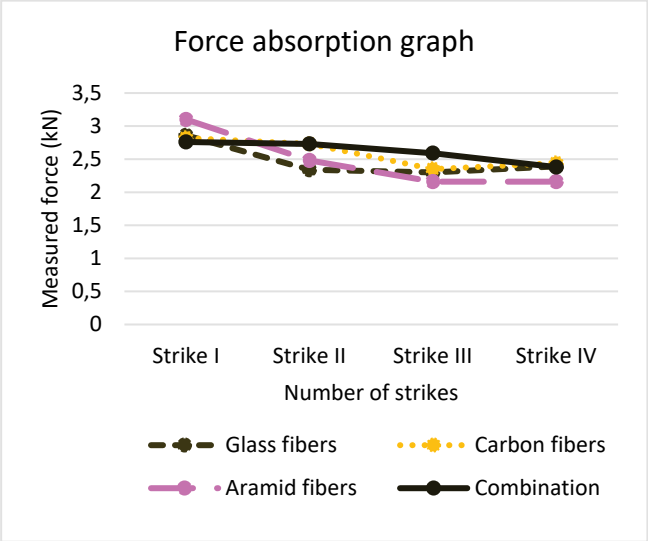


Figure 7 Presentation of the results of the third test cycle

3.2 Comparison of Results

The test results showed that the thickness of the foam under the composite material affects the value of the force loaded by the sensor. The thicker the foam the more energy it absorbs.

Through three test cycles, it was concluded that the most energy was absorbed by carbon fiber materials as seen in the first cycle results, where there was no PE foam, and especially in the second cycle results where there was a 10 mm thick foam under the tile. The results of the second cycle show the largest discrepancies between the results of individual materials and it can be concluded that carbon fiber is the most appropriate choice when choosing materials for making a protective helmet because it absorbed the impact force, which served in the final decision.

The combination of aramid and carbon fibers had slightly worse results, however if the helmet needs to have some characteristics (toughness, wear resistance) that aramid fibers can provide, the choice of combination of carbon and aramid fibers may be better than choosing the carbon fibers themselves to make the helmet.

Aramid fibers and glass fibers absorbed the impact force less, so the results for these materials were worse.

By comparing the strength of the material and the amount of energy absorbed, the tests confirmed the findings on the relationship between strength and energy absorption. The higher the strength of the material, the greater the absorption.

4 CONCLUSION

Through examination of the impact absorption of composite materials, it was concluded that the materials that

best absorb the force are carbon fibers. For this reason, it was decided to use carbon fiber to make a multifunctional protective helmet due to the force absorption ability and high strength (3000-5000 MPa), which guarantees maximum user safety.

It was concluded that further research of composite materials is possible and necessary using other criteria such as; price, appearance, comfort, reliability, etc.

5 REFERENCES

[1] Šercer, M. (2019). *Proizvodnja kompozitnih tvorevina*, Zagreb, Croatia, Faculty of Mechanical Engineering and Naval Architecture. (in Croatian)
[2] Smojver, I. (2007). *Mehanika kompozitnih materijala*, Zagreb, Croatia, Faculty of Mechanical Engineering and Naval Architecture. (in Croatian)
[3] Šimić, V. (2002). *Otpornost materijala I (2nd edition)*, Zagreb, Croatia, Školska knjiga. (in Croatian)
[4] https://www.sestan-busch.hr/ (2021) Prelog, Croatia.
[5] Schaeffler. (2014). *Technical guide*, Nurnberg, Germany.
[6] Liu, P. S. & Chen, G. F. (2014). *Porous materials - Processing and Applications*. Butterworth-Heinemann, Oxford.
[7] Wardle, M. W. (2000). *Comprehensive composite materials*. Germany.

Author's contacts:

Božo Bujanić, M.Sc. Ing. mech.
Sestan-Busch d.o.o.
Industrijska zona 3,
40323 Prelog, Croatia
E-mail: bozo.bujanic@fsb.hr

Matija Košak, M.Sc. Ing. mech.
(Corresponding author)
Sestan-Busch d.o.o.
Industrijska zona 3,
40323 Prelog, Croatia
E-mail: kosak95@gmail.com

ISSN 1846-6168 (Print), ISSN 1848-5588 (Online)
https://doi.org/10.31803/tg-20.....

14pt
14pt

Article Title Only in English (Style: Arial Narrow, Bold, 14pt)

14pt

Ivan Horvat, Thomas Johnson, Marko Marić (Style: Arial Narrow, Normal, 10pt)

14pt

Abstract: Article abstract contains maximum of 150 words and is written in the language of the article. The abstract should reflect the content of the article as precisely as possible. TECHNICAL JOURNAL is a trade journal that publishes scientific and professional papers from the domain(s) of mechanical engineering, electrical engineering, civil engineering, multimedia, logistics, etc., and their boundary areas. This document must be used as the template for writing articles so that all the articles have the same layout. (Style: Arial Narraw, 8pt)

8pt

Keywords: keywords in alphabetical order (5-6 key words). Keywords are generally taken from the article title and/or from the abstract. (Style: Arial Narraw, 8pt)

10pt
10pt

1 INTRODUCTION (Article Design)

(Style: Arial Narrow, Bold, 10pt)

10pt

(Tab 6 mm) The article is written in Latin script and Greek symbols can be used for labelling. The length of the article is limited to eight pages of international paper size of Letter (in accordance with the template with all the tables and figures included). When formatting the text the syllabification option is not to be used.

10pt

1.1 Subtitle 1 (Writing Instructions)

(Style: Arial Narrow, 10pt, Bold, Align Left)

10pt

The document format is Letter with margins in accordance with the template. A two column layout is used with the column spacing of 10 mm. The running text is written in Times New Roman with single line spacing, font size 10 pt, alignment justified.

Article title must clearly reflect the issues covered by the article (it should not contain more than 15 words).

Body of the text is divided into chapters and the chapters are divided into subchapters, if needed. Chapters are numbered with Arabic numerals (followed by a period). Subchapters, as a part of a chapter, are marked with two Arabic numerals i.e. 1.1, 1.2, 1.3, etc. Subchapters can be divided into even smaller units that are marked with three Arabic numerals i.e. 1.1.1, 1.1.2, etc. Further divisions are not to be made.

Titles of chapters are written in capital letters (uppercase) and are aligned in the centre. The titles of subchapters (and smaller units) are written in small letters (lowercase) and are aligned left. If the text in the title of the subchapter is longer than one line, no hanging indents.

10pt

Typographical symbols (bullets), which are being used for marking an item in a list or for enumeration, are placed at a beginning of a line. There is a spacing of 10pt following the last item:

- Item 1
- Item 2
- Item 3

10pt

The same rule is valid when items are numbered in a list:

1) Item 1
2) Item 2
3) Item 3

10pt

1.2 Formatting of Pictures, Tables and Equations

(Style: Arial Narrow, 10pt, Bold, Align Left)

10pt

Figures (drawings, diagrams, photographs) that are part of the content are embedded into the article and aligned in the centre. In order for the figure to always be in the same position in relation to the text, the following settings should be defined when importing it: text wrapping / in line with text.

Pictures must be formatted for graphic reproduction with minimal resolution of 300 dpi. Pictures downloaded from the internet in ratio 1:1 are not suitable for print reproduction because of unsatisfying quality.

10pt

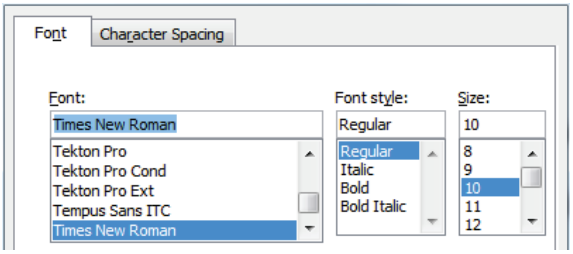


Figure 1 Text under the figure [1]
(Style: Arial Narraw, 8pt, Align Centre)

10pt

The journal is printed in black ink and the figures have to be prepared accordingly so that bright tones are printed in a satisfactory manner and are readable. Figures are to be in colour for the purpose of digital format publishing. Figures in the article are numbered with Arabic numerals (followed by a period).

Text and other data in tables are formatted - Times New Roman, 8pt, Normal, Align Center.

When describing figures and tables, physical units and their factors are written in italics with Latin or Greek letters,

while the measuring values and numbers are written upright.

10pt

Table 1 Table title aligned centre

(Style: Arial Narraw, 8pt, Align Centre)

	1	2	3	4	5	6
ABC	ab	ab	ab	ab	ab	ab
DEF	cd	cd	cd	cd	cd	cd
GHI	ef	ef	ef	ef	ef	ef

10 pt

Equations in the text are numbered with Arabic numerals inside the round brackets on the right side of the text. Inside the text they are referred to with equation number inside the round brackets i.e. ".... from Eq. (5) follows ...." (Create equations with MathType Equation Editor - some examples are given below).

10pt

$$F_{\text{avg}}(t, t_0) = \frac{1}{t}\int_{t_0}^{t_0+t} F\left[q(\tau), p(\tau)\right] \mathrm{d}\tau, \tag{1}$$

$$\cos\alpha + \cos\beta = 2\cos\frac{\alpha+\beta}{2}\cdot\cos\frac{\alpha-\beta}{2}, \tag{2}$$

$$(\boldsymbol{AB})^{\mathrm{T}} = \boldsymbol{B}^{\mathrm{T}}\boldsymbol{A}^{\mathrm{T}}. \tag{3}$$

10pt

Variables that are used in equations and also in the text or tables of the article are formatted as *italics* in the same font size as the text.

10pt

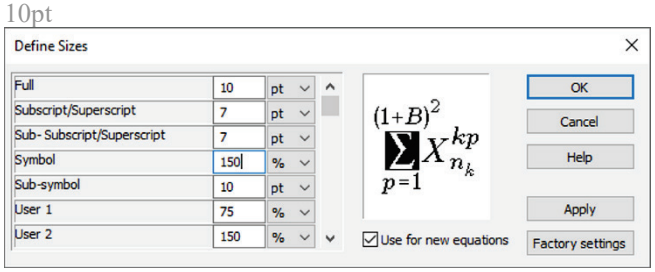


Figure 2 The texts under figures

(Style: Arial Narraw, 8pt, Align Centre)

10pt

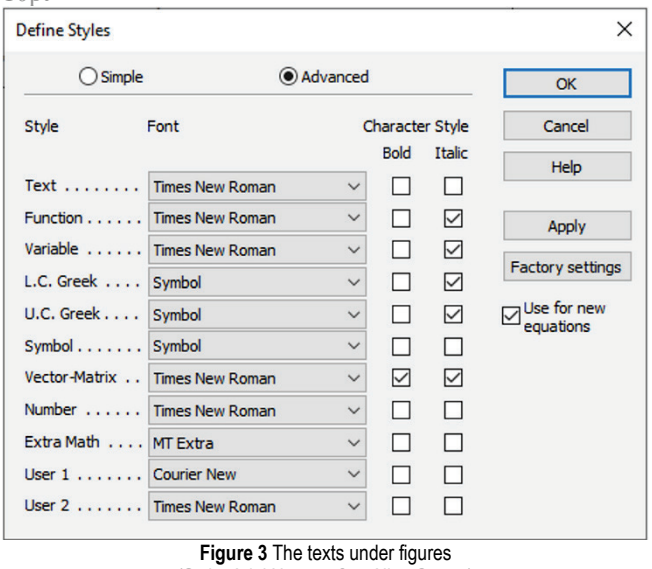


Figure 3 The texts under figures

(Style: Arial Narraw, 8pt, Align Centre)

Figures and tables that are a part of the article have to be mentioned inside the text and thus connected to the content i.e. " … as shown in Fig. 1…" or "data from Tab. 1…" and similar.

10pt

2 PRELIMINARY ANNOTATION

10pt

Article that is offered for publication cannot be published beforehand, be it in the same or similar form, and it cannot be offered at the same time to a different journal. Author or authors are solely responsible for the content of the article and the authenticity of information and statements written in the article.

Articles that are accepted for publishing are classified into four categories: original scientific papers, preliminary communications, subject reviews and professional papers.

Original scientific papers are articles that according to the reviewer and the editorial board contain original theoretical or practical results of research. These articles need to be written in such a way that based on the information given, the experiment can be repeated and the results described can be achieved together with the author's observations, theoretical statements or measurements.

Preliminary communication contains one or more pieces of new scientific information, but without details that allow recollection as in original scientific papers. Preliminary communication can give results of an experimental research, results of a shorter research or research in progress that is deemed useful for publishing.

Subject review contains a complete depiction of conditions and tendencies of a specific domain of theory, technology or application. Articles in this category have an overview character with a critical review and evaluation. Cited literature must be complete enough to allow a good insight and comprehension of the depicted domain.

Professional paper can contain a description of an original solution to a device, assembly or instrument, depiction of important practical solutions, and similar. The article need not be related to the original research, but it should contains a contribution to an application of known scientific results and their adaptation to practical needs, so it presents a contribution to spreading knowledge, etc.

Outside the mentioned categorization, the Editorial board of the journal will publish articles of interesting content in a special column. These articles provide descriptions of practical implementation and solutions from the area of production, experiences from device application, and similar.

10pt

3 WRITING AN ARTICLE

10pt

Article is written in the English language and the terminology and the measurement system should be adjusted to legal regulations, standards and the International System of Units (SI) (Quantities and Units: ISO 80 000 - from Part 1 to Part 14). The article should be written in third person.

Introduction contains the depiction of the problem and an account of important results that come from the articles that are listed in the cited literature.

Main section of the article can be divided into several parts or chapters. Mathematical statements that obstruct the reading of the article should be avoided. Mathematical statements that cannot be avoided can be written as one or more addendums, when needed. It is recommended to use an example when an experiment procedure, the use of the work in a concrete situation or an algorithm of the suggested method must be illustrated. In general, an analysis should be experimentally confirmed.

Conclusion is a part of the article where the results are being given and efficiency of the procedure used is emphasized. Possible procedure and domain constraints where the obtained results can be applied should be emphasized.

10pt

4 RECAPITULATION ANNOTATION

10pt

In order for the articles to be formatted in the same manner as in this template, this document is recommended for use when writing the article. Finished articles written in MS Word for Windows and formatted according to this template must be submitted using our The Paper Submission Tool (PST) (https://tehnickiglasnik.unin.hr/authors.php) or eventually sent to the Editorial board of the Technical Journal to the following e-mail address: tehnickiglasnik@unin.hr

The editorial board reserves the right to minor redaction corrections of the article within the framework of prepress procedures. Articles that in any way do not follow these authors' instructions will be returned to the author by the editorial board. Should any questions arise, the editorial board contacts only the first author and accepts only the reflections given by the first author.

10pt

5 REFERENCES (According to APA)

10pt

The literature is cited in the order it is used in the article. No more than 35 references are recommended. Individual references from the listed literature inside the text are addressed with the corresponding number inside square brackets i.e. "… in [7] is shown …". If the literature references are web links, the hyperlink is to be removed as shown with the reference number 8. Also, the hyperlinks from the e-mail addresses of the authors are to be removed. In the literature list, each unit is marked with a number and listed according to the following examples (omit the subtitles over the references – they are here only to show possible types of references):

9pt

[1] See http://www.bibme.org/citation-guide/apa/

[2] See http://sites.umuc.edu/library/libhow/apa_examples.cfm

[3] (Style: Times New Roman, 9pt, according to APA)

[4] Amidzic, O., Riehle, H. J., & Elbert, T. (2006). Toward a psychophysiology of expertise: Focal magnetic gamma bursts as a signature of memory chunks and the aptitude of chess players. *Journal of Psychophysiology, 20*(4), 253-258. https://doi.org/10.1027/0269-8803.20.4.253

[5] Reitzes, D. C. & Mutran, E. J. (2004). The transition to retirement: Stages and factors that influence retirement adjustment. *International Journal of Aging and Human Development, 59*(1), 63-84. Retrieved from http://www.baywood.com/journals/PreviewJournals.asp?Id=0091-4150

[6] Jans, N. (1993). *The last light breaking: Life among Alaska's Inupiat Eskimos*. Anchorage, AK: Alaska Northwest Books.

[7] Miller, J. & Smith, T. (Eds.). (1996). *Cape Cod stories: Tales from Cape Cod, Nantucket, and Martha's Vineyard*. San Francisco, CA: Chronicle Books.

[8] Chaffe-Stengel, P. & Stengel, D. (2012). *Working with sample data: Exploration and inference*. https://doi.org/10.4128/9781606492147

[9] Freitas, N. (2015, January 6). People around the world are voluntarily submitting to China's Great Firewall. Why? Retrieved from http://www.slate.com/blogs/future_tense/2015/01/06/tencent_s_wechat_worldwide_internet_users_are_voluntarily_submitting_to.html (Style: Times New Roman, 9pt, according to APA)

10pt

10pt

Authors' contacts:

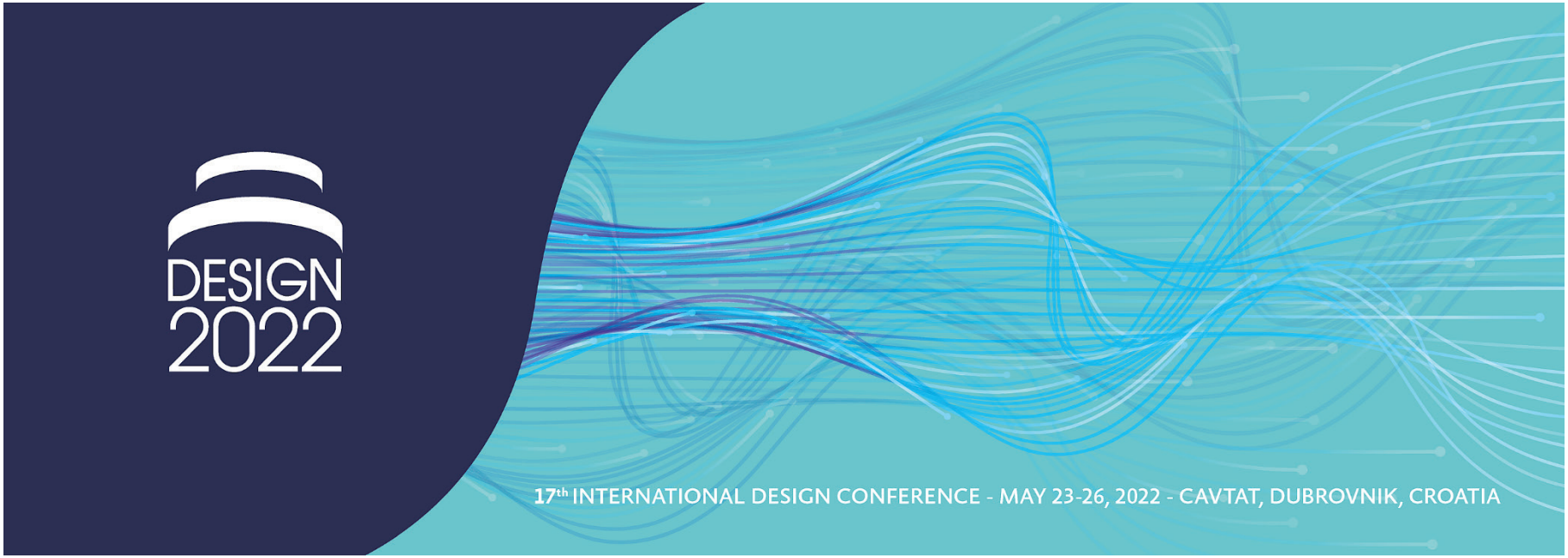
8pt

Full Name, title
Institution, company
Address
Tel./Fax, e-mail

8pt

Full Name, title
Institution, company
Address
Tel./Fax, e-mail

Note: Gray text should be removed in the final version of the article because it is for guidance only.



TOPICS

DESIGN SUPPORT TOOLS AND METHODS
- Configuration and modularisation
- Design for additive manufacturing
- PDM/PLM
- Requirements and change management
- Usage and integration of supportive technologies

INDUSTRIAL DESIGN
- User-centred design
- Aesthetics and visual impressions
- Product semantics
- User experience design
- Emotional design

DESIGN INFORMATION AND KNOWLEDGE
- Representations of information and knowledge
- Decision-making rationale and support
- Knowledge-intensive design
- Knowledge-based engineering
- Emerging IT technologies in knowledge management

HUMAN BEHAVIOUR IN DESIGN
- Human factors in design
- Designer's attitudes and skills
- Design thinking
- Design cognition and problem-solving
- Designer's activity

DESIGN THEORY AND RESEARCH METHODS
- Multidisciplinary research approaches
- Design theories and models
- Experimental design research
- Design typology
- New infrastructure for design research

ENGINEERING DESIGN PRACTICE
- Geometrical modelling and CAD
- Simulation-based design
- Advanced visualisation and virtualisation
- Case studies of design methods application
- Best design practices from industry

DESIGN FOR SUSTAINABILITY
- Sustainability awareness
- Design for social equity and cohesion
- Design for circular economy
- Technology and sustainable society
- Product-service systems

DESIGN2022

SYSTEMS ENGINEERING AND DESIGN
- Architecting complex engineering systems
- Simulation within complex systems
- Model-based systems engineering (MBSE)
- Cyber-physical systems design
- Approaches to socio-technical systems design

DESIGN ORGANISATION AND MANAGEMENT
- Organisational and design processes
- Product development models and strategies
- Market and business implications
- Global product development
- Agile management

ARTIFICIAL INTELLIGENCE AND DATA-DRIVEN DESIGN
- Artificial intelligence in product development
- Generative design and topological optimisation
- Data-driven design process
- Knowledge discovery and data mining in design
- Smart systems for Industry 4.0

DESIGN CREATIVITY
- Creative design processes
- Cognitive processes in design creativity
- Supporting design creativity and innovation
- Creativity assessment and measurement
- Bioinspired design

COLLABORATIVE DESIGN
- Design teams
- Design communication and collaborative processes
- Co-design
- Multidisciplinary/Interdisciplinary/Transdisciplinary collaboration
- Open/Social innovation

DESIGN FOR HEALTHCARE
- Healthcare ecosystems
- Healthcare design
- Healthcare services
- Use of advanced technologies in healthcare
- Life sciences and design

DESIGN EDUCATION
- Competency development
- Digital learning and ICT in education
- Project-based learning
- Adopting different teaching and learning environments
- Lifelong and organisational learning

INVITATION

By tradition, DESIGN Conference is a forum for discussion and further development of design knowledge from cognition and philosophy to methods and tools, from research theory to practice.

The transition from known and comfortable to unknown and challenging is ubiquitous. It is challenging every aspect of our being. How can design research and practice respond to changes, influence wellness, ensure sustainable development, reimagine the future, rethink the product design and development?

How to improve design methodologies, tools, projects, and processes? How to develop products and services to make the world a healthier place? Which competencies, information, and communication technologies are needed? What is the impact on everyday design work? Which social and legal issues should be considered? How will we teach future designers, communicate ideas and share knowledge? How to adapt to the new normal?

Applied, theoretical, and results-oriented papers from academia and industry, based on thorough analysis or argumentation, will be considered for the conference programme. The submitted papers should fit into one of the proposed conference topics. It is expected that these specific topics are extensive and nonexhaustive.

A list of examples is added to illustrate the core topics. It is required explicitly from all contributors to show how they contribute to the overall research within these areas. A detailed description of topics and instructions for online submission is available at www.designconference.org.

Programme chairs welcome the high-quality submissions covering substantial, original, and previously unpublished research.

Rigour academic research should provide designers with the next generation of methods and tools appropriate to the demands.

PROGRAMME

The DESIGN Conference provides an interactive environment where participants proactively create opportunities to share design knowledge and new cross-disciplinary research that leads to innovation.

PLENARY SESSIONS

The new ideas and visions will be presented by the keynote speakers.

TOPIC ORIENTED SESSIONS

Will host papers selected around common research questions in order to foster discussion.

WORKSHOPS

DESIGN 2022 workshops will promote integration of different views, approaches and methods. Workshop coordinators could invite selected presentations and demonstrations in order to stimulate the debate as well as to propose any format of delivery that inspires interaction. The workshops will be organised on the 23rd of May.

PHD STUDENTS' FORUM

The forum will be a unique opportunity for younger researchers and PhD students to discuss their research questions and ideas with experienced researchers, practitioners and R&D managers in order to facilitate their research efforts.

THE DESIGN DEBATE

The purpose of the design debate is to investigate in a forensic manner some key topics that affect the engineering design research community. Two opponents and the debate moderator will be distinguished key players in the community presenting evidence for or against a particular topic.

INDUSTRIAL FORUM

The industrial forum will be an opportunity to discuss industrial views, needs and expectations of design research, tracing emerging trends in industrial innovation and the right strategies for a sustainable future. The forum will offer a platform for debate among decision makers, practitioners and academics about the future of design research, needs and expectations.

REVIEWING POLICY

The papers will be accepted on the double-blind review basis made by the members of the Scientific Advisory Board.

The review criteria will be the novelty and level of contribution, validity of conclusions, industrial or application perspective and formal qualities of the contribution.

DESIGN Conference papers are published online at Cambridge Core Journals pages as: Proceedings of the Design Society: DESIGN Conference. All papers are indexed in SCOPUS and WOS - CPCI and referenced in CrossRef with DOI identifier.

Selected papers will be recommended for publication in international journals.

STEP 01 Full paper submission deadline **November 15, 2021**

STEP 02 Final acceptance of papers **February 1, 2022**

STEP 03 Publish-ready papers **February 25, 2022**

STEP 04 Final conference programme **April 2022**

STEP 05 **DESIGN 2022 CONFERENCE** **May 23-26, 2022**

PROGRAMME CHAIRS

P. John Clarkson
University of Cambridge, GBR

Tim McAloone
Technical University of Denmark, DNK

Julie Stal-Le Cardinal
CentraleSupélec, FRA

Sandro Wartzack
Friedrich-Alexander-University of Erlangen-Nuremberg, DEU

Mario Štorga
University of Zagreb, HRV

Dorian Marjanović
University of Zagreb, HRV

CONFERENCE VENUE

Hotel Croatia Cavtat
Frankopanska ul. 10, 20210 Cavtat, Croatia

ORGANISING SECRETARIAT CONTACT

Faculty of Mechanical Engineering
and Naval Architecture
10000 Zagreb, I. Lučića 5, CROATIA
Phone: +385 1 6168 432

design2022@fsb.hr
www.designconference.org

the Design Society a worldwide community

FSB cad lab

TEHNIČKI GLASNIK / TECHNICAL JOURNAL – GODIŠTE / VOLUME 15 – BROJ / ISSUE 4

PROSINAC 2021 / DECEMBER 2021 – STRANICA / PAGES 449-584

Sveučilište Sjever

SVEUČILIŠTE SJEVER / UNIVERSITY NORTH – CROATIA – EUROPE

ISSN 1846-6168 (PRINT) / ISSN 1848-5588 (ONLINE)

TEHNICKIGLASNIK@UNIN.HR – HTTP://TEHNICKIGLASNIK.UNIN.HR