

THE INFLUENCE MONITORING PROBLEM

László Hajdu¹

InnoRenew CoE

Livade 6, 6310 Izola, Slovenia

E-mail: laszlo.hajdu@innorenew.eu

Miklós Krész²

InnoRenew CoE

Livade 6, 6310 Izola, Slovenia

E-mail: miklos.kresz@innorenew.eu

Abstract: A new problem called influence monitoring is defined and studied for the Generalized Independent Cascade Problem. It is shown that the objective function of the problem is submodular by which the greedy algorithm can ensure an approximate ratio. The efficient implementation of the greedy method is described from algorithm design point of view.

Keywords: infection processes, influence maximization, greedy algorithm, network optimisation, network immunization

1 INTRODUCTION

The study of network infection processes plays an important role in several fields; in addition to epidemiology [9], it was successfully applied in sociology (spread of opinions) [8] or business and economics (marketing campaign [6] or risk management [3]), to mention a few. The related research questions were formulated as a discrete optimisation problem in 2003 in the pioneering work of Kempe, Kleinberg and Tardos [10]. The so-called influence maximization is defined by the following way: determine the most influential vertices in a directed edge-weighted graph (where edge weights are reflecting the infection probabilities) with respect to an infection process changing the status of the vertices according to a well-defined function of the incoming edges and incident vertices. Kempe et al proved that the problem is NP-hard, however for a wide class of infection processes the greedy algorithm provides a solution with a guaranteed approximation ratio. During the last 15 years the above work exposed an extraordinary interest in the scientific community and several generalization of the original problem were developed (for a review see e.g. [1]).

In this paper, instead of finding the most influential vertices, we will be focusing to identify those vertices through which the highest expected number of vertices are accessible in “infection chains”. This “influence monitoring task” is different from the original problem, as the optimal solution is given by those vertices which are the best candidates to be “monitored” to decrease the influence of an infection process (instead of finding those vertices which are the most influential for an “outbreak”). Concerning the infection mechanism our study will concentrate on the generalization of the most widely used Independent Cascade model [6], however our approach can be generalized for all diffusion processes under the Generalized Threshold Model [10]. In this Generalized Independent Cascade Model each vertex has an initial “a priori” infection probability. We will prove that the greedy algorithm provides the same approximation factor as the influence maximization problem has and we will develop an efficient implementation of this method.

¹ Also at University of Primorska, Slovenia and University of Szeged, Hungary.

² Also at University of Primorska, Slovenia and University of Szeged, Hungary.

The organization of this paper is as follows. In Section 2 we will present the necessary formal background on influence maximization and formally define the influence monitoring problem. In Section 3 as a main result we will develop the greedy method with all the technical details and will describe its approximability power. Finally, in Section 4 we will give a short conclusion. Because of space constraints proofs are omitted.

2 INFLUENCE MAXIMIZATION AND MONITORING

In this paper we will consider directed weighted general graphs. Our terminology will be standard, the set of vertices and set of edges will be denoted by $V(G)$ and $E(G)$, respectively. We are considering stochastic diffusion processes on networks (see e.g. [2]) in general, but because of space restrictions in this paper we will be focusing on one of the basic (and most popular) models, the Independent Cascade model. In this model the weight $w_{u,v} \in [0,1]$ for the edge (u,v) directed from u to v is expressing the probability by which u is forwarding the diffusion to v through this edge.

As an iterative process the *Independent Cascade (IC)* model [10] starts with a set S_0 of active vertices and in the i^{th} iteration step the set of (previously inactive) vertices S_i will be activated by the vertices of S_{i-1} . The process will be terminated once S_i is empty. During the process a vertex u from S_{i-1} has a single chance to activate a neighbouring vertex v with probability $w_{u,v}$. If more than one vertex is trying to activate v in the same iteration, the attempts are realized in a random order and independently. The process is not deterministic, however the expected number $\sigma(S_0)$ of activated vertices can be used for a well-defined optimisation problem called *influence maximization* [10]: Given a positive integer k , find a set of vertex set S with size k such that $\sigma(S)$ is maximized.

Influence maximization is a hard problem, even for a fixed set S , the computation $\sigma(S)$ is #P-complete [5]. Nevertheless, in their pioneering paper Kempe et al [10] showed that by random sampling and direct simulation of the diffusion process, $\sigma(S)$ can be arbitrarily approximated. Furthermore, they have proved that using the greedy hill-climbing method (in each step choosing the vertex providing the largest marginal increase in $\sigma(S)$, the optimum can be approximated within a factor of $(1 - 1/e)$ (where e is the base of the natural logarithm). They have actually shown that the set function $\sigma(S)$ is a monotone nonnegative submodular function. This property of $\sigma(S)$ guarantees the above approximability by a classical result of Nemhauser et al [12]. A function that maps subsets of a finite ground set to real numbers is called *submodular* if the marginal gain by adding an extra element to a set S cannot be higher than the marginal gain by adding the same element to a subset of S . For more details about submodular optimisation see [11].

The IC model was generalized in [4] with assigning infection probabilities to the vertices as well. In the *Generalized Independent Cascade (GIC)* model the weighted directed graph is extended with *a priori infection probabilities* w_v for all $v \in V(G)$ and each vertex v becomes active independently with probability w_v at the beginning of the process. Having a random choice of infected vertices according to the a priori probabilities, the process is executed by the IC model. Concerning the stochastic feature of the model, at the end of the process an *a posteriori probability* w_v^* is obtained for each vertex v . As a generalization the sum of the values w_v^* provides the generalized function $\sigma(w)$. We will suppose that a graph G is given with infection probabilities on the edges as well as on the vertices for the rest of the paper.

With respect to the above stochastic process it can be a natural question to describe the “local influence” of vertices. Concerning the interpretation of the IC model an “instance infection” is a branching process (see e.g. [7] Chapter 21) an unweighted directed forest as an

(unweighted) subgraph of G . Starting from the initially infected vertices a particular realization of infection in the cascade corresponds to a forest where each iteration will determine the next level of this forest. Therefore, concerning the whole stochastic process of G , it is a distribution of unweighted forests sampled from G . Each forest will be referred as a *forest instance infection* or simply *forest instance*.

Now considering a forest instance F and a vertex set $S \subseteq V(F)$, the *local influence value* $\mu_F(S)$ is defined as the number of descendants of S in F , i.e. the number of vertices accessible by a directed path from a vertex of S . Note that the elements of S are also counted in this manner (with paths of length zero). Finally, the *local influence index* $\mu_G(S)$ for the weighted graph G and $S \subseteq V(G)$ is the expected value of $\mu_F(S)$ for a random forest instance F in G . In this paper our goal is to optimize the local influence index:

In the *influence monitoring problem* for a given weighted graph G and positive integer k , determine the vertex set S with size k for which $\mu_G(S)$ provides the maximum value.

3 THE GREEDY ALGORITHM

We will be developing a greedy heuristic with a guaranteed approximation ratio. For that we are extending the concept of Kempe et al [10] for graph sampling with “live” and “blocked” edges (see also “complete simulation” in [4]). Concerning the attempt of infecting vertex v by vertex u with a probability $w_{u,v}$, we can consider it as flipping a coin of bias $w_{u,v}$ and generating unweighted edge to be “live” with probability $w_{u,v}$. Since each attempt is independent, we can “flip” for each edge independently and generating an unweighed graph instance. Concerning the result of GIC it has no relevance when the independent coin flips are realized, we can make it at the beginning of the process. In such a graph instance an infection from a vertex u to a vertex v is activated if and only if there exists a directed path from u to v . However, in contrast to influence maximization, in our influence monitoring problem the probability of activating by a particular edge in a graph instance is important (concerning multiple attempts to the same vertex); we will discuss it later.

Extending the sampling methodology of Kempe et al [10] by a *graph instance infection or graph instance* in short we will mean an unweighted graph sampling each edge (u,v) according to $w_{u,v}$ and determining initial activated vertices in a random manner according to a priori infection probabilities. Similarly to influence maximization and the original sampling of Kempe et al [10], graph G is equivalent to the a distribution of graph instances G' and $\mu_G(S)$ can be obtained as a linear combination of different $\mu_{G'}(S)$ values according to this distribution. The advantage of this approach is twofold. On one hand it provides a framework for approximating $\mu_G(S)$ by simulation (see complete simulation in [4]). On the other hand as linear combination of submodular functions is also submodular, it will be enough for an arbitrary graph instance G' that $\mu_{G'}(S)$ is submodular. As a consequence, by the results of [12] and considering the monotone and nonnegative properties of $\mu_G(S)$ we will get the guaranteed approximation for the greedy method.

Concerning the efficient implementation of the greedy method as well as proving submodularity of $\mu_{G'}(S)$ we will need to solve the following problem.

Problem 1. *Given a graph instance G' of G and $S \subseteq V(G)$. Determine a function $\mu_{G'}^*(S, v)$ which satisfies the following conditions for each vertex $v \in V(G)$:*

- $\mu_{G'}(S) = \sum_{v \in S} \mu_{G'}^*(S, v)$
- $\mu_{G'}(S \cup \{v\}) = \mu_{G'}(S) + \mu_{G'}^*(S, v)$ for each $v \in V(G) - S$

In order to solve the above problem, starting from the initially infected vertices of G' build up the directed breadth first search forest of G' . We will keep those edges only which are connecting two neighbouring levels of the forest. This reduced graph will be denoted by $BF[G']$ and the set of edges of $BF[G']$ is denoted by $BF[E']$. This graph is representing the collection of potential infection instances by IC in G' in such a way that the initially infected vertices are on $level_1$. Vertices in $level_2$ will be infected from $level_1$ and generally the vertices in $level_{i+1}$ are infected from $level_i$.

Suppose now that we have r levels in $BF[G']$. Clearly, for any vertex v in $level_r$, $\mu_{G'}^*(S, v) = 1$. Notice that starting from $level_r$ we can recursively backward calculate $\mu_{G'}^*(S, v)$. Indeed, if the indegree of v is d , then the infection can be realized by any incoming edge to v with probability $1/d$. By this observation it is easy to organize the calculation, which is described in details in Algorithm 1.

Algorithm 1

Input: Breadth-first reduction $BF[G']$ of graph instance G' with r levels and dedicated vertex set $S \subseteq V(G')$

Output: For each vertex $v \in V(G')$ the value of a function $\mu_{G'}^*(S, v)$ satisfying conditions described in Problem 1

For each vertex v at $level_r$ let $\mu_{G'}^*(S, v) = 1$

for $i=r$ **downto** 2 **do**

for each vertex v at $level_i$

for each incoming edge (u, v)

let $label_{u,v} = 1/d$ (where d is the indegree of v in $BF[G']$)

for each vertex u at $level_{i-1}$

$\mu_{G'}^*(S, u) = 1 + \sum_{w \notin S \& (u,w) \in BF[E']} label_{u,w} \cdot \mu_{G'}^*(S, u')$

end for

It can be proved by induction that the function $\mu_{G'}^*(S, v)$ produced by Algorithm 1 has the required properties as summarized below.

Proposition 1. *For each $v \in V(G')$, the function $\mu_{G'}^*(S, v)$ in Algorithm 1 satisfies the conditions of Problem 1 and the method runs in linear time of $E(G')$.*

Analyzing Algorithm 1, based on the conditions defined in Problem 1 we can obtain the submodular property.

Proposition 2. *Function $\mu_{G'}(S)$ is submodular.*

As discussed earlier, the submodularity of $\mu_G(S)$ follows from Proposition 2 and it is also clear that $\mu_G(S)$ is monotone and non-negative.

Corollary 1. *Function $\mu_G(S)$ is monotone, non-negative and submodular.*

By Corollary 1 we can design the greedy method with guaranteed approximation described in Algorithm 2. Note that instead of the mean value we are using the sum for $\mu_G(S, v)$ in order to simplify calculation.

Algorithm 2

Input: Weighted graph G and positive integer k

Output: Vertex set S with cardinality k by greedy with respect to $\mu_G(S)$

Let $S = \emptyset$

For $i=1$ to k **do**

 Generate graph instances

 For each graph instance G' and for each vertex $v \in V(G)$, calculate $\mu_{G'}^*(S, v)$ according to *Algorithm 1*

 Let $\mu_G^*(S, v)$ be the sum of the $\mu_{G'}^*(S, v)$ values of all graph instances for each vertex $v \in V(G)$

 Let $S = S \cup \{v\}$ with v having maximum in $\mu_G^*(S, v)$

end for

Now we can summarize our finding by a direct consequences of the previous results.

Theorem 1. *Algorithm 1 provides a solution approximating the influence monitoring problem within a factor of $(1 - 1/e - \varepsilon)$, where where e is the base of the natural logarithm and ε is an arbitrary small positive number depending on the simulation.*

Note that the scale of approximation can depend on the simulation (the number and distribution of the graph instances), however, similarly to the influence maximization problem [10], this gap can be arbitrarily small.

4 CONCLUSION

In this paper we have introduced the influence monitoring problem for the Generalized Independent Cascade Model. We have proved that the objective function for this problem is nonnegative, monotone and submodular, thus using the classical result of Nemhauser et al, it is shown that the greedy method provides a solution within an approximation factor of $(1 - 1/e - \varepsilon)$, where where e is the base of the natural logarithm and ε is an arbitrary small positive number depending on the simulation. As a further research we are extending the results for a wider class of problems and will show the efficiency of the methodology with a comprehensive testing on artificial and real networks.

Acknowledgement

The Authors gratefully acknowledge the European Commission for funding the InnoRenew CoE project (Grant Agreement #739574) under the Horizon2020 Widespread-Teaming program, and the Republic of Slovenia (Investment funding of the Republic of Slovenia and the European Union of the European Regional Development Fund), and they are also grateful for the support of Slovenian Research Agency (ARRS) through grants N1-0093, N2-0171 and J2-2504.

References

1. Banerjee, Suman et al. *A survey on influence maximization in a social network*. Knowledge and Information Systems 62 (2020): 3417-3455.
2. L. E. Blume, *The statistical mechanics of strategic interaction*. Games and Economic Behavior, 5(3):387–424, 1993.
3. A. Bóta et al. *Applications of the inverse infection problem on bank transaction networks*. Central European Journal of Operations Research 23.2 (2015): 345-356.
4. A. Bóta, M. Krész, and A. Pluhár. *Approximations of the Generalized Cascade Model*. Acta Cybernetica 21 (2013): 37-51.
5. Chen, Wei et al. *Scalable influence maximization for prevalent viral marketing in large-scale social networks*. Proceedings of the 16th ACM SIGKDD international conference on Knowledge discovery and data mining (2010).

6. P. Domingos, M. Richardson, *Mining the Network Value of Customers*. Proceedings of the 7th International Conference on Knowledge Discovery and Data Mining, ACM (2001) 57-66.
7. D. Easley, and J. Kleinberg. *Networks, Crowds, and Markets* (2010).
8. M. Granovetter, *Threshold models of collective behavior*. American Journal of Sociology 83(6) (1978) 1420-1443.
9. M. Keeling and K. Eames. *Networks and epidemic models*. Journal of the Royal Society, Interface / the Royal Society, 2:295–307, 10 2005.
10. D. Kempe, J. Kleinberg, E. Tardos, *Maximizing the Spread of influence through a Social Network*. Proceedings of the ninth ACM SIGKDD international conference on Knowledge discovery and data mining (2003) 137-146.
11. E. Mossel, and S. Roch. *Submodularity of Influence in Social Networks: From Local to Global*. SIAM J. Comput. 39 (2010): 2176-2188.
12. Nemhauser, G. et al. *An analysis of approximations for maximizing submodular set functions—I*. Mathematical Programming 14 (1978): 265-294.

Proceedings SOR

Rupnik V. and L. Bogataj (Editors): The 1st Symposium on Operational Research, SOR'93. Proceedings. Ljubljana: Slovenian Society Informatika, Section for Operational Research, 1993, 310 pp.

Rupnik V. and M. Bogataj (Editors): The 2nd International Symposium on Operational Research in Slovenia, SOR'94. Proceedings. Ljubljana: Slovenian Society Informatika, Section for Operational Research, 1994, 275 pp.

Rupnik V. and M. Bogataj (Editors): The 3rd International Symposium on Operational Research in Slovenia, SOR'95. Proceedings. Ljubljana: Slovenian Society Informatika, Section for Operational Research, 1995, 175 pp.

Rupnik V., L. Zadnik Stirn and S. Drobne (Editors.): The 4th International Symposium on Operational Research in Slovenia, SOR'97. Proceedings. Ljubljana: Slovenian Society Informatika, Section for Operational Research, 1997, 366 pp. ISBN 961-6165-05-4.

Rupnik V., L. Zadnik Stirn and S. Drobne (Editors.): The 5th International Symposium on Operational Research SOR'99, Proceedings. Ljubljana: Slovenian Society Informatika, Section for Operational Research, 1999, 300 pp. ISBN 961-6165-08-9.

Lenart L., L. Zadnik Stirn and S. Drobne (Editors.): The 6th International Symposium on Operational Research SOR'01, Proceedings. Ljubljana: Slovenian Society Informatika, Section for Operational Research, 2001, 403 pp. ISBN 961-6165-12-7.

Zadnik Stirn L., M. Basti and S. Drobne (Editors): The 7th International Symposium on Operational Research SOR'03, Proceedings. Ljubljana: Slovenian Society Informatika, Section for Operational Research, 2003, 424 pp. ISBN 961-6165-15-1.

Zadnik Stirn L. and S. Drobne (Editors): The 8th International Symposium on Operational Research SOR'05, Proceedings. Ljubljana: Slovenian Society Informatika, Section for Operational Research, 2005, 426 pp. ISBN 961-6165-20-8.

Zadnik Stirn L. and S. Drobne (Editors): The 9th International Symposium on Operational Research SOR'07, Proceedings. Ljubljana: Slovenian Society Informatika, Section for Operational Research, 2007, 460 pp. ISBN 978-961-6165-25-9.

Zadnik Stirn L., J. Žerovnik, S. Drobne and A. Lisec (Editors): The 10th International Symposium on Operational Research SOR'09, Proceedings. Ljubljana: Slovenian Society Informatika, Section for Operational Research, 2009, 604 pp. ISBN 978-961-6165-30-3.

Zadnik Stirn L., J. Žerovnik, J. Povh, S. Drobne and A. Lisec (Editors): The 11th International Symposium on Operational Research SOR'11, Proceedings. Ljubljana: Slovenian Society Informatika, Section for Operational Research, 2011, 358 pp. ISBN 978-961-6165-35-8.

Zadnik Stirn L., J. Žerovnik, J. Povh, S. Drobne and A. Lisec (Editors): The 12th International Symposium on Operational Research SOR'13, Proceedings. Ljubljana: Slovenian Society Informatika, Section for Operational Research, 2013, 390 pp. ISBN 978-961-6165-40-2.

Zadnik Stirn L., J. Žerovnik, M. Kljajič Borštnar, S. Drobne (Editors): The 13th International Symposium on Operational Research SOR'15, Proceedings. Ljubljana: Slovenian Society Informatika, Section for Operational Research, 2015, 559 pp. ISBN 978-961-6165-45-7.

Zadnik Stirn L., J. Žerovnik, M. Kljajič Borštnar, S. Drobne (Editors): The 14th International Symposium on Operational Research SOR'17, Proceedings. Ljubljana: Slovenian Society Informatika, Section for Operational Research, 2017, 567 pp. ISBN 978-961-6165-50-1.

Zadnik Stirn L., M. Kljajič Borštnar, J. Žerovnik, S. Drobne, J. Povh (Editors): The 15th International Symposium on Operational Research SOR'19, Proceedings. Ljubljana: Slovenian Society Informatika, Section for Operational Research, 2019, 618 pp. ISBN 978-961-6165-55-6.



ISBN 978-961-6165-57-0

9 17 89 61 611 6 5 7 0 1

Proceedings SOR '21



Proceedings of the 16th International Symposium
on OPERATIONAL RESEARCH in Slovenia

SOR'21

September 22-24, 2021

Edited by:

S. Drobne • L. Zadnik Stirn • M. Kljajič Borštnar • J. Povh • J. Žerovnik

SOR '21 Proceedings

*The 16th International Symposium on Operational Research
in Slovenia*

September 22 - 24, 2021, Online

Edited by:

S. Drobne, L. Zadnik Stirn, M. Kljajić Borštar, J. Povh and J. Žerovnik



Slovenian Society INFORMATIKA (SDI)
Section for Operational Research (SOR)

© 2021 Samo Drobne – Lidija Zadnik Stirn – Mirjana Kljajić Borštnar – Janez Povh – Janez Žerovnik

Proceedings of the 16th International Symposium on Operational Research in Slovenia, SOR'21 in Slovenia, September 22 - 24, 2021, Online.

Organiser: Slovenian Society INFORMATIKA – Section for Operational Research, SI-1000 Ljubljana, Litostrojska cesta 54, Slovenia (www.drustvo-informatika.si/sekcije/sor/)

Co-organiser: University of Maribor, Faculty of Organizational Sciences, SI-4000 Kranj, Kidričeva cesta 55a, Slovenia (<http://www.fov.um.si/>)

Co-organiser: University of Ljubljana, Faculty of Mechanical Engineering, SI-1000 Ljubljana, Aškerčeva cesta 6, Slovenia (<https://www.fs.uni-lj.si/>)

First published in Slovenia in 2021 by Slovenian Society INFORMATIKA – Section for Operational Research, SI 1000 Ljubljana, Litostrojska cesta 54, Slovenia (www.drustvo-informatika.si/sekcije/sor/)

CIP - Kataložni zapis o publikaciji
Narodna in univerzitetna knjižnica, Ljubljana

519.8(082)
519.8:005.745(082)
519.81:519.233.3/.5(082)

INTERNATIONAL Symposium on Operational Research in Slovenia (16 ; 2021 ; online)
SOR '21 proceedings : the 16th International Symposium on Operational Research in Slovenia : September 22 - 24, 2021, online / [organiser] Slovenian Society Informatika (SDI), Section for Operational Research (SOR), [co-organiser University of Maribor, Faculty of Organizational Sciences [and] University of Ljubljana, Faculty of Mechanical Engineering] ; edited by S. Drobne ... [et al.] - Ljubljana : Slovenian Society Informatika, Section for Operational Research, 2021

ISBN 978-961-6165-57-0
COBISS.SI-ID 75727107

All rights reserved. No part of this book may be reproduced, stored in a retrieval system, or transmitted by any other means without the prior written permission of the copyright holder.

Proceedings of the 16th International Symposium on Operational Research in Slovenia (SOR'21) is cited in: ISI (Index to Scientific & Technical Proceedings on CD-ROM and ISI/ISTP&B online database), Current Mathematical Publications, Mathematical Review, MathSci, Zentralblatt für Mathematic / Mathematics Abstracts, MATH on STN International, CompactMath, INSPEC, Journal of Economic Literature

Technical editor: Samo Drobne
Designed by: Samo Drobne
Printed by: BISTISK d.o.o., Ljubljana, Slovenia
Number of copies printed: 160

The 16th International Symposium on Operational Research in Slovenia - SOR '21
September 24 - 26, 2021, Online

Program Committee:

- L. Zadnik Stirn, University of Ljubljana, Biotechnical Faculty, Ljubljana, Slovenia, chair
M. Kljajić Borštnar, University of Maribor, Faculty of Organizational Sciences, Kranj, Slovenia, co-chair
J. Žerovnik, University of Ljubljana, Faculty of Mechanical Engineering, Ljubljana, Slovenia, co-chair
J. Arnerić, University of Zagreb, Faculty of Economics and Business, Zagreb, Croatia
F. Berberich, PRACE – The Partnership for Advanced Computing in Europe, Brussels, Belgium
Marija Bogataj, University of Ljubljana, Faculty of Economics, and INRISK, Slovenia
M. Bohanec, Jožef Stefan Institute, Department of Knowledge Technologies, Ljubljana, Slovenia
D. Bokal, University of Maribor, Faculty of Natural Sciences and Mathematics, and DataBitLab d.o.o.,
Maribor, Slovenia
S. Cabello, University of Ljubljana, Faculty of Mathematics and Physics, Ljubljana, Slovenia
K. Cechlarova, P. J. Šafarik University, Faculty of Science, Košice, Slovakia
T. Csendes, University of Szeged, Department of Applied Informatics, Szeged, Hungary
V. Čančer, University of Maribor, Faculty of Business and Economics, Maribor, Slovenia
S. Drobne, University of Ljubljana, Faculty of Civil and Geodetic Engineering, Ljubljana, Slovenia
K. Dumičić, University of Zagreb, Faculty of Economics and Business, Zagreb, Croatia
L. Ferbar Tratar, University of Ljubljana, Faculty of Economics, Ljubljana, Slovenia
H. Gaspars-Wieloch, Poznan University of Economics and Business, Poznan, Poland
N. Herakovič, University of Ljubljana, Faculty of Mechanical Engineering, Ljubljana, Slovenia
E. Hontoria, Technical University of Cartagena, Business Management Department, Cartagena, Spain
T. Illes, Corvinus Centre for Operations, Corvinus University of Budapest, Budapest, Hungary
J. Jablonsky, University of Economics, Faculty of Informatics and Statistics, Prague, Czech Republic
J. Jozefowska, Poznan University of Technology, Poznan, Poland, EURO vice-president
S. Klavžar, University of Ljubljana, Faculty of Mathematics and Physics, Ljubljana, Slovenia
A. Košir, University of Ljubljana, Faculty of Electrical Engineering, Ljubljana, Slovenia
J. Kušar, University of Ljubljana, Faculty of Mechanical Engineering, Ljubljana, Slovenia
U. Leopold-Wildburger, University of Graz, Graz, Austria
Z. Lukač, University of Zagreb, Faculty of Economics and Business, Zagreb, Croatia
J. Michnik, University of economics, Katowice, Poland
M. Pejić Bach, University of Zagreb, Faculty of Economics and Business, Zagreb, Croatia
T. Perić, University of Zagreb, Faculty Economics and Business, Zagreb, Croatia
S. Pivac, University of Split, Faculty of Economics, Department for Quantitative Methods, Split, Croatia
J. Povh, University of Ljubljana, Faculty of Mechanical Engineering, Ljubljana, Slovenia
U. Rajkovič, University of Maribor, Faculty of Organizational Sciences, Kranj, Slovenia
Č. Rozman, University of Maribor, Faculty of Agriculture and life sciences, Maribor, Slovenia
J. Šilc, Jožef Stefan Institute, Computer Systems Department, Ljubljana, Slovenia
T. Škrinjarić, Croatian National Bank, Zagreb, Croatia
T. Trzaskalik, University of Economics, Department of Operational Research, Katowice, Poland
T. Wachowicz, University of Economics, Department of OR, Katowice, Poland
G.W. Weber, Poznan University of Technology, Faculty of Engineering Management, Poznan, Poland

Organizing Committee:

- P. Gorjanc, University of Maribor, Faculty of Organizational Sciences, Kranj, Slovenia, chair
S. Drobne, University of Ljubljana, Faculty of Civil and Geodetic Engineering, Ljubljana, Slovenia, co-chair
N. Fileš, Slovenian Society INFORMATIKA, Ljubljana
M. Kljajić Borštnar, University of Maribor, Faculty of Organizational Science, Kranj, Slovenia
J. Povh, University of Ljubljana, Faculty of Mechanical Engineering, Ljubljana, Slovenia
L. Zadnik Stirn, University of Ljubljana, Biotechnical Faculty, Ljubljana, Slovenia

The 16th International Symposium on Operational Research in Slovenia - SOR '21
September 24 - 26, 2021, Online

Reviewers:

Wellington Alves, Business School, Instituto Politécnico de Viana do Castelo; ALGORITMI Research Centre, Universidade do Minho, Portugal

Josip Arnerić, University of Zagreb, Faculty of Economics and Business, Zagreb, Croatia

Marija Bogataj, University of Ljubljana, Faculty of Economics, and INRISK, Slovenia

Marko Bohanec, Jožef Stefan Institute, Department of Knowledge Technologies, Ljubljana, Slovenia

D. Bokal, University of Maribor, Faculty of Natural Sciences and Mathematics, and DataBitLab d.o.o., Maribor, Slovenia

Katarína Cechlárová, P. J. Šafarik University, Faculty of Science, Košice, Slovakia

Vesna Čančer, University of Maribor, Faculty of Economics and Business

Ćukušić Maja, University of Split, Faculty of Business, Economics and Tourism, Split, Croatia

Samo Drobne, University of Ljubljana, Faculty of Civil and Geodetic Engineering, Ljubljana, Slovenia

Ksenija Dumičić, University of Zagreb, Faculty of Economics and Business, Zagreb, Croatia

Eisenberg-Nagy Marianna, Corvinus University of Budapest, Corvinus Centre for Operations Research

Helena Gaspars-Wieloch, Poznan University of Economics and Buiness, Poznan, Poland

Eloy Hontoria, Technical University of Cartagena, Business Management Department, Cartagena, Spain

Tibor Illés, Corvinus University of Budapest, Corvinus Centre for Operations Research

Mario Jadrić, University of Split, Faculty of Business, Economics and Tourism, Split, Croatia

Janja Jerebic, University of Maribor, Faculty of Organizational Sciences, Kranj, Slovenia

Veljko Jeremić, University of Belgrade, Faculty of Organizational Sciences, Belgrade, Serbia

Sandi Klavžar, University of Ljubljana, Faculty of Mathematics and Physics, Ljubljana, Slovenia

Mirjana Kljajić Borštnar, University of Maribor, Faculty of Organizational Sciences, Kranj, Slovenia

Andrej Košir, University of Ljubljana, Faculty of Electrical Engineering, Ljubljana, Slovenia

Vasja Leban, University of Ljubljana, Biotechnical Faculty, Ljubljana, Slovenia

Zrinka Lukač, University of Zagreb, Faculty of Economics and Business, Zagreb, Croatia

Karmen Pažek, University of Maribor, Faculty of Agriculture and Life Sciences

Mirjana Pejić Bach, Faculty of Economics & Business, University of Zagreb, Croatia

Tunjo Perić, University of Zagreb, Faculty Economics and Business, Department of Informatics, Zagreb, Croatia

Snježana Pivac, University of Split, Faculty of Economics, Split, Croatia

Janez Povh, University of Ljubljana, Faculty of Mechanical Engineering, Ljubljana, Slovenia

Uroš Rajkovič, University of Maribor, Faculty of Organizational Sciences, Kranj, Slovenia

Vladislav Rajkovič, University of Maribor, Faculty of Organizational Sciences, Kranj, Slovenia

Helena Sofia Rodrigues, Business School, Instituto Politécnico de Viana do Castelo; Center for Research and Development in Mathematics and Applications (CIDMA), Universidade de Aveiro

Črtomir Rozman, University of Maribor, Faculty of Agriculture and Life Sciences

Darja Rupnik, University of Ljubljana, Faculty of Mechanical Engineering, Ljubljana, Slovenia

Ângela Silva, Business School, Instituto Politécnico de Viana do Castelo; COMEGI, Universidade Lusíada, Portugal

Jurij Šilc, Jožef Stefan Institute, Computer Systems Department, Ljubljana, Slovenia

Tadeusz Trzaskalik, University of Economics, Department of Operational Research Katowice, Poland

Lidija Zadnik Stirn, University of Ljubljana, Biotechnical Faculty, Ljubljana, Slovenia

Anja Žnidaršič, University of Maribor, Faculty of Organizational Sciences, Kranj, Slovenia

Janez Žerovnik, University of Ljubljana, Faculty of Mechanical Engineering, Ljubljana, Slovenia

The 16th International Symposium on Operational Research in Slovenia - SOR '21
September 24 - 26, 2021, Online

Chairs:

- Wellington Alves, Business School, Instituto Politécnico de Viana do Castelo; ALGORITMI Research Centre, Universidade do Minho, Portugal
- Marija Bogataj, University of Ljubljana, Faculty of Economics, and INRISK, Slovenia
- David Bogataj, University of Ljubljana, Faculty of Economics, and INRISK, Slovenia
- Drago Bokal, University of Maribor, Faculty of Natural Sciences and Mathematics, and DataBitLab d.o.o., Maribor, Slovenia
- Vesna Čančer, University of Maribor, Faculty of Economics and Business
- Maja Čukušič, University of Split, Faculty of Business, Economics and Tourism, Split, Croatia
- Samo Drobne, University of Ljubljana, Faculty of Civil and Geodetic Engineering, Ljubljana, Slovenia
- Ksenija Dumičić, University of Zagreb, Faculty of Economics and Business, Zagreb, Croatia
- Eisenberg-Nagy Marianna, Corvinus University of Budapest, Corvinus Centre for Operations Research
- Helena Gaspars-Wieloch, Poznan University of Economics and Business, Poznan, Poland
- Tibor Illés, Corvinus University of Budapest, Corvinus Centre for Operations Research
- Mario Jadrić, University of Split, Faculty of Business, Economics and Tourism, Split, Croatia
- Janja Jerebic, University of Maribor, Faculty of Organizational Sciences, Kranj, Slovenia
- Veljko Jeremić, University of Belgrade, Faculty of Organizational Sciences, Belgrade, Serbia
- Sandi Klavžar, University of Ljubljana, Faculty of Mathematics and Physics, Ljubljana, Slovenia
- Mirjana Kljajić Borštnar, University of Maribor, Faculty of Organizational Sciences, Kranj, Slovenia
- Andrej Košir, University of Ljubljana, Faculty of Electrical Engineering, Ljubljana, Slovenia
- Zrinka Lukač, University of Zagreb, Faculty of Economics and Business, Zagreb, Croatia
- Karmen Pažek, University of Maribor, Faculty of Agriculture and Life Sciences
- Mirjana Pejić Bach, Faculty of Economics & Business, University of Zagreb, Croatia
- Tunjo Perić, University of Zagreb, Faculty Economics and Business, Department of Informatics, Zagreb, Croatia
- Snježana Pivac, University of Split, Faculty of Economics, Split, Croatia
- Janez Povh, University of Ljubljana, Faculty of Mechanical Engineering, Ljubljana, Slovenia
- Helena Sofia Rodrigues, Business School, Instituto Politécnico de Viana do Castelo; Center for Research and Development in Mathematics and Applications (CIDMA), Universidade de Aveiro
- Črtomir Rozman, University of Maribor, Faculty of Agriculture and Life Sciences
- Ângela Silva, Business School, Instituto Politécnico de Viana do Castelo; COMEGI, Universidade Lusíada, Portugal
- Tadeusz Trzaskalik, University of Economics, Department of Operational Research Katowice, Poland
- Tomasz Wachowicz, University of Economics in Katowice, Katowice, Poland
- Lidija Zadnik Stirn, University of Ljubljana, Biotechnical Faculty, Ljubljana, Slovenia
- Anja Žnidaršič, University of Maribor, Faculty of Organizational Sciences, Kranj, Slovenia
- Janez Žerovnik, University of Ljubljana, Faculty of Mechanical Engineering, Ljubljana, Slovenia

Preface

This volume, Proceedings of the 16th International Symposium on Operational Research, called SOR'21, contains papers presented at SOR'21 (<https://sor.fov.um.si/>), organised by Slovenian Society INFORMATIKA (SDI), Section for Operational Research (SOR), University of Maribor, Faculty of Organisational Sciences, Kranj, Slovenia (FOV), and University of Ljubljana, Faculty of Mechanical Engineering, Ljubljana, Slovenia (UL FS). The SOR'21 symposium, held 22-24 September 2021, was originally planned to take place in Bled, Slovenia, but was moved online due to the situation of COVID-19 in Slovenia and beyond. The volume contains blind peer-reviewed papers or abstracts of papers presented at the symposium.

The opening address at SOR'21 was given by Prof. Dr. Lidija Zadnik Stirn, President of SOR, Mr. Niko Schlamberger, President of SDI, representatives of FOV and UL FS, Prof. Dr. Mario Jadrić, President of Croatian Operational Research Society (CRORS), Dr Sarah Fores, manager of The Association of European Operational Research Societies (EURO), and presidents/representatives of some others Operational Research Societies from abroad.

SOR'21 is the scientific event in the field of Operational Research, another in the traditional series of biennial international OR conferences organised in Slovenia by SDI-SOR. It is the continuation of fifteen previous symposia. The main objective of SOR'21 is to promote knowledge, interest and education in the field of OR in Slovenia, Europe and worldwide in order to build the intellectual and social capital essential for maintaining the identity of OR, especially at a time when interdisciplinary cooperation is proclaimed as particularly important for solving problems in today's challenging times. By joining IFORS and EURO, the SDI-SOR has also agreed to collaborate with different disciplines, i.e., to balance the depth of theoretical knowledge in OR and the understanding of theory, methods, and problems in other fields within and outside OR. We believe that SOR'21 creates the advantage of these goals, contributes to the quality and reputation of OR by presenting and sharing new developments, opinions and experiences in the theory and practise of OR.

SOR'21 was highlighted by five distinguished keynote speakers. The first part of Proceedings SOR'21 contains invited abstracts, presented by five outstanding scientists: Assist. Prof. Nikolina Ban, University of Innsbruck (UIBK), Department of Atmospheric and Cryospheric Sciences, Innsbruck, Austria, Assist. Prof. Vedran Kojić, University of Zagreb, Faculty of Economics & Business, Zagreb, Croatia, Prof. Panos Patrinos, KU Leuven, Department of Electrical Engineering (ESAT), STADIUS Center for Dynamical Systems, Signal Processing and Data Analytics, Leuven, Belgium, Prof. Suresh P. Sethi, Eugene McDermott Chair Professor of Operations Management, Director, Center of Intelligent Supply Networks, Naveen Jindal School of Management, The University of Texas at Dallas, Dallas, USA, and Prof. Jerneja Žganec Gros, Alpineon Ltd, Ljubljana, Slovenia.

The Proceedings includes 118 papers or abstracts by 240 authors. Most of the authors of the contributed papers came from Slovenia (82), then Croatia (52), Hungary (23), Portugal (23), Serbia (17), Poland (9), Czech Republic (8), Slovak Republic (7), Spain (6), Netherlands (4), Bosnia and Herzegovina (2), Austria (1), Belgium (1), France (1), Germany (1), Romania (1), Ukraine (1), United Kingdom (1), and United States of Amerika (1). The papers published in the Proceedings are divided into Plenary Lectures (5 abstracts), eleven special sessions: Application of Operational Research in Smart Cities (6 papers), Computational Mathematical Optimization (7 papers and 6 abstracts), Data Science – Methodologies and Case Studies (10 papers), Graph Theory and Algorithms (2 papers),

High-Performance Computing and Big Data (3 papers), Industry & Society 5.0: Optimization in Industrial and Human Environments (6 papers), International Projects in Operations Research (2 papers), Lessons Learned from the COVID-19 Pandemic: Applications of Statistical and OR Methods (8 papers), Logistics and Sustainability (9 papers), Operational Research in Ageing Studies and Social Innovations (5 papers), Operations Research in Agricultural Economics and Farm Management (5 papers), and eight sessions: Econometric Models and Statistics (6 papers), Environment and Social Issues (5 papers), Finance and Investments (6 papers), Location and Transport, Graphs and their Applications (5 papers), Mathematical Programming and Optimization (5 papers and 1 abstract), Multi-Criteria Decision-Making (10 papers), Theory of Games (3 papers), and Problems Approaching OR (3 papers).

Proceedings of the previous fifteen International Symposia on Operational Research organised by the Slovenian Section on Operational Research, listed at <https://www.drustvo-informatika.si/sekcije/sor/sor-publikacijepublications/>, are indexed in the following secondary and tertiary publications: Current Mathematical Publications, Mathematical Review, Zentralblatt fuer Mathematik/ Mathematics Abstracts, MATH on STN International and CompactMath, INSPEC. It is expected that Proceedings SOR'21 will be covered by the same bibliographic databases.

The success of the scientific events at SOR'21 and of the present conference proceedings should be seen because of joint efforts. On behalf of the organisers, we would like to express our sincere gratitude to all those who assisted us in the preparation of the event. Without the dedicated and advice of the active members of the Slovenian Operations Research Section, we would not have been able to attract so many top-class speakers from all over the world. Many thanks to them. In addition, we would like to express our deepest gratitude to the prominent keynote speakers, the members of the Programme and Organising Committees, the reviewers who improved the quality of SOR'21 with their useful suggestions, the section chairs and all the numerous people - far too many to list individually here - who helped in organizing of the 16th International Symposium on Operational Research SOR'21 and compiling this proceedings. Finally, we thank the authors for their efforts in preparing and presenting the papers that made the 16th Symposium on Operational Research SOR'21 a success.

We would like to give special thanks to the Partnership for Advanced Computing in Europe (PRACE) for their financial support.

Ljubljana and Kranj, September 22, 2021

*Samo Drobne
Lidija Zadnik Stirn
Mirjana Kljajić Borštnar
Janez Povh
Janez Žerovnik
(Editors)*

Contents

Plenary Lectures **1**

<i>Nikolina Ban</i> Mountain Climate at the Kilometer-Scale Grid Spacing	3
<i>Vedran Kojić</i> Application of Basic Mathematical Inequalities to Selected Problems in Economics	4
<i>Panos Patrinos</i> Algorithms for Large-Scale Structured Nonconvex Optimization	5
<i>Suresh P. Sethi</i> Managing with Incomplete Inventory Information	6
<i>Jerneja Žganec Gros</i> Speech Synthesis in Language Digitisation: The Slovenian Use Case	7

Special Session 1: Application of Operational Research in Smart Cities **9**

<i>Aleš Groznik, Eva Jelerčič, Sarina Kaloh, Maša Klun and Anton Manfreda</i> Examining the Gap Between Smart City Definitions and Smart City Indexes: A Call Towards Unified Index	11
<i>Ivan Kekez and Daniela Garbin Praničević</i> Investigating Singular Value Decomposition as a Tool for Data Management in Tourism	17
<i>Ivan Kekez, Mario Jadrić and Maja Čukušić</i> Demonstration Potential of Simulation Modelling in the Urban Mobility Domain	23
<i>Antonija Kvasina, Tea Mijač and Marko Hell</i> Developing System Dynamics Model for Waste Management in Tourism-Oriented Smart City	29
<i>Tea Mijač, Ivana Ninčević Pašalić and Luka Tomat</i> Selection of IoT Platforms in Smart Cities: Multi-Criteria Decision Making	35
<i>Polona Pavlovčič Prešeren</i> Group Method of Data Handling for Modeling GNSS Site-Specific Quality Parameters	41

Special Session 2: Computational Mathematical Optimization **47**

<i>Kolos Cs. Ágoston and Marianna E. Nagy</i> Mixed Integer Linear Programming Formulation for K-means Cluster Problem	49
<i>Kolos Csaba Ágoston and Márton Gyetvai</i> Comparison of an Iterative Heuristic and Joint Optimization in the Optimization of Bonus-Malus Systems	55
<i>Márton Benedek, Péter Biró, Walter Kern and Daniel Paulusma</i> Computing International Kidney Exchange Schemes	61
<i>Kristóf Druzsín, Péter Biró, Rita Fleiner and Xenia Klimentova</i> Simulations for Measuring Efficiency of International Kidney Exchange Programmes	62

<i>Dávid Csercsik</i> Heuristics for Combinatorial Auction-Based Channel Allocation Approaches in Multi-Connective Wireless Environments	68
<i>Marianna E.-Nagy and Anita Varga</i> A Family of Long-Step Interior Point Algorithms for Linear Programming	74
<i>Marianna E.-Nagy and Anita Varga</i> A Numerical Comparison of Long-Step Interior Point Algorithms for Linear Optimization	75
<i>László Á. Kóczy and Balázs R. Sziklai</i> Power and Preferences	81
<i>Petra Renáta Rigó, Tibor Illés and Zsolt Darvay</i> Algebraic Equivalent Transformation Technique in Case of Sufficient Linear Complementarity Problems	83
<i>Tamás Solymosi</i> Sensitivity of Fair Prices in Assignment Markets	84
<i>Dávid Tollner and Tibor Illés</i> Bounded Pooling Problem	85
<i>Roland Török, Tibor Illés and Petra Renáta Rigó</i> Implementation of Primal-Dual Interior-Point Algorithm for Solving Sufficient Linear Complementarity Problems	86
<i>Ajda Zavrtanik Drglin, Romi Koželj, Martin Pečar and Gregor Mrak</i> Making the Next Step in Finding the Best Route	92

Special Session 3: Data Science – Methodologies and Case Studies **99**

<i>Aljaž Ferencek and Mirjana Kljajić Borštnar</i> Open Government Data Impact Areas Identification with Data Mining Techniques	101
<i>Blaž Gašperlin, Andreja Pucihar and Mirjana Kljajić Borštnar</i> SMEs Readiness in Utilizing Digital Technologies and Data in Digital Transformation	107
<i>Petra Kašparová and Petr Průcha</i> Design of a Model for Implementation of Business Intelligence Methods in Decision-Making Processes	113
<i>László Kovács</i> Performance Testing of Feature Selection Algorithms for Generalized Additive Models	119
<i>Zoltán Madari and Veronika Szádóczkiné Varga</i> Empirical Analysis of the Hungarian Insurance Market	125
<i>Boris Peršak, Uroš Rajkovič and Davorin Kofjač</i> Factors of Motor Policies Casco Coverage Risk Exposures	130
<i>Maja Pervan and Petra Babić</i> Evaluation of Efficiency and Its Determinants in Croatian Hotel Industry	136
<i>Maja Pervan and Ena Jurić</i> Determinants of Tourism Demand in Croatia	144
<i>Petr Průcha and Petra Kašparová</i> Use of Emotion in Designing BI Dashboards	151

<i>Jovana Zoroja, Mirjana Pejic Bach and Ivan Miloloža</i> Seeking Health Information over the Internet: Cluster Analysis Approach to Analyzing Differences Among European Countries	157
-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------	-----

Special Session 4: Graph Theory and Algorithms **165**

<i>Peter Czimmermann and Michal Lichner</i> Critical Edges in Weighted Center Problems	167
<i>Boštjan Gabrovšek, Aljoša Peperko and Janez Žerovnik</i> 2-Rainbow Independent Domination Numbers of Some Graphs	173

Special Session 5: High-Performance Computing and Big Data **179**

<i>Tomaž Čegovnik, Andrej Dobrovoljc, Janez Povh and Matic Rogar</i> Electricity Consumption Prediction Using Artificial Intelligence	181
<i>Timotej Hrga and Janez Povh</i> On Using Hypermetric Inequalities in a Cutting-Plane Algorithm for Max-Cut	188
<i>Andrej Kastrin, Rok Hribar, Gregor Papa and Janez Povh</i> Bibliographic Data Clustering Based on Symmetric Non-Negative Matrix Tri-Factorization	194

Special Session 6: Industry & Society 5.0: Optimization in Industrial and Human Environments **201**

<i>Drago Bokal, Markus Chimani and Alen Vegi Kalamar</i> On the Didactic Value of Crossing Critical Graphs	203
<i>Tamara Čurlin, Ivan Miloloža and Helena Nikolić</i> Increasing Efficiency of Health Care Management with the Online Scheduling for Medical Services: Impact of Age and Occupation	209
<i>Aleksandar Dojčinović, Martin Prelog, Maj Lopatič and Uroš Rajković</i> Smart House for Older and People with Disabilities	215
<i>Janja Jerebic, Špela Kajzer, Monika Vogrinec and Drago Bokal</i> Longitudinal Dynamics between Linearly Ordered Classes	221
<i>Ana Sousa, Cristina Rodrigues, Senhorinha Teixeira and Dominique Besson</i> Influence of National Culture in Supply Chain Internal Integration	227
<i>Tena Žužek, Janez Kušar and Tomaž Berlec</i> Guidelines for Agile Concurrent Product Development in SMEs	233

Special Session 7: International Projects in Operations Research **239**

<i>Alenka Tratnik, Anja Žnidaršič, Janja Jerebic, Uroš Rajković, Alenka Baggia, Dragana Gak, Tatjana Grbić, Nataša Duraković and Slavica Medić</i> Predictors of Email Communication Skills among Slovenian and Serbian Students	241
-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------	-----

<i>Anja Žnidaršič, Borut Werber, Alenka Baggia, Maryna Vovk, Vanja Bevanda and Lukasz Zakonnik</i>	
The Intention to Use Microchip Implants: Model Extensions after the Pandemics	247

Special Session 8: Lessons Learned from the COVID-19 Pandemic: Applications of Statistical and OR Methods **253**

<i>Matúš Bilka and Zdravka Aljinović</i>	
The Role of Cryptocurrencies in the Portfolio Optimization During the COVID-19 Pandemic	255
<i>Alenka Brezavšček, Janja Jerebic, Gregor Rus and Anja Žnidaršič</i>	
In-Class and Online Teaching of Mathematics – A Comparison of Students’ Outcomes at the Midterm Exams	262
<i>L.N. Bulder and N.M. van Dijk</i>	
On the COVID effect for OT-ICU systems	268
<i>Ivana Lazarevic, Milica Maricic and Marina Ignjatovic</i>	
Segmenting Centennials Based on their Consumer Behaviour During COVID-19 Pandemics: The Case of Confectionery Industry	276
<i>Jelena Minović</i>	
The Response of Market Volatility to the COVID-19 Pandemic	282
<i>Gordana Savić, Kristina Dobrilović, Bisera Andrić Gušavac, Minja Marinović and Milena Popović</i>	
Measuring Efficiency of Health Care System of OECD Member Countries During Pandemic COVID-19	288
<i>Nikola Zornić, Nataša Bojković and Tanja Živojinović</i>	
Assessing the Impact of COVID-19 Lockdown on Air Pollutant Emissions in Cities: The Case of Europe’s Cleanest and Most Polluted Countries	294
<i>Berislav Žmuk</i>	
Does the COVID-19 Discriminate by Gender? Croatian and Slovenian Case	300

Special Session 9: Logistics and Sustainability **307**

<i>Wellington Alves, Ângela Silva and Helena Sofia Rodrigues</i>	
Consumer’s Willingness to Engage in the Circular Economy: The Higher Education Outlooks	309
<i>Ana Rita Castro, Claudia Duarte, Senhorinha Teixeira and Ângela Silva</i>	
Urgent Orders Impact on Materials Management in Portuguese Construction Sector - Case Study	315
<i>Balázs Dávid, Olivér Ósz and Máté Hegyháti</i>	
Scheduling of Waste Wood Processing Facilities with Overlapping Jobs	321
<i>Joana Nascimento, Nuno Frazão, Senhorinha Teixeira and Ana Cecilia Ribeiro</i>	
Order Variation and Flexibility Rules Dashboard	327
<i>Ana Órfão, Ângela Silva and Wellington Alves</i>	
The Role of Intermodal Transportation on Reducing CO ₂ Emissions	333
<i>Vitoria Packer do Amaral, Ana Cristina Ferreira and Bruna Ramos</i>	
A PDCA-Based Approach to Improve the Logistic Supply of an Assembly Line in the Automobile Sector: A Case Study	339

<i>Eduardo Pintado, Lia Coelho de Oliveira and Jorge Esparteiro Garcia</i> Enhancing Environmental Sustainability and E-Commerce Deliveries through the Use of EPP Boxes in a Darkstore	345
<i>Tiago Duarte Silva Vieira, Ângela Silva, Jorge Esparteiro Garcia and Wellington Alves</i> Methodological Framework for Measuring Regional Logistics Performance	351
<i>Ana Rita Vasconcelos, Ângela Silva and Helena Sofia Rodrigues</i> Volunteering in Humanitarian Logistics: A Structural Equation Modeling	357

Special Session 10: Operational Research in Ageing Studies and Social Innovations **363**

<i>David Bogataj and Valerija Rogelj</i> The Social Value of Specialised Housing for Older Adults	365
<i>Samo Drobne and Marija Bogataj</i> Older Adults Perspectives in Optimisation of Migration Flow	371
<i>Lana Kordić and Josipa Višić</i> Efficiency of Croatian Nursing Homes - DEA Analysis	377
<i>Marija Milavec Kapun, Vladislav Rajkovič, Olga Šušteršič, Rok Drnovšek and Uroš Rajkovič</i> Multi-Criteria Self-Care Decision Model of Patients with Chronic Diseases	383
<i>Renata Možanić and David Bogataj</i> Forecasting the Homecare Utilization: Case for Varaždin County	389

Special Session 11: Operations Research in Agricultural Economics and Farm Management **395**

<i>Jure Brečko and Jaka Žgajnar</i> Farm Model and Risk Management Strategies on a Mixed Farm Type	397
<i>Ana Novak and Luka Juvančič</i> Multi-Criteria Evaluation of Alternative Scenarios for Closing Loops of Agricultural and Forestry Biomass	404
<i>Boris Prevolšek, Maja Žibert, Karmen Pažek, Aleksandar Maksimović, Adis Puška and Črtomir Rozman</i> Multi Criteria Assessment of Sustainable Development of Ethno-Villages in Bosnia and Herzegovina	410
<i>Janja Rudolf and Andrej Udovč</i> Testing MCDM Model for Evaluating the Potential of Coordinated Agri-Environmental Approaches Among Farmers on Two Case Studies from Netherland	416
<i>Maja Žibert, Boris Prevolšek, Andrej Škraba and Črtomir Rozman</i> Strategies for Structural Changes in Agricultural Holdings as a Farm Tourism Model Development	422

Session 1: Econometric Models and Statistics **427**

<i>Darja Boršič and Lea Žižek</i> Determinants of Economic Development: An Application of Limited Dependent Variable Models	429
<i>Michaela Chocholatá and Andrea Furková</i> Educational Inequalities Across the EU Regions: Mixed GWR Approach	435
<i>Ksenija Dumičić and Ivana Cunjak Mataković</i> Approaches to Data Transformations and their Impact on the Skewness Statistic for Seriously Skewed Distributions: Selected Cryptocurrencies' Data Explored	441
<i>Elza Jurun, Nada Ratković and Lidija Bekavac</i> Strategy Europa 2020 and Economic Development from a National Point of View	447
<i>Kosovka Ognjenović</i> Gender Wage Inequality in the Labor Market of a Post-Socialist Economy	453
<i>Petar Sorić and Marija Logarušić</i> Tipping Points in the Croatian Political Sentiment: When, Why, and does the Economy have Anything to do with it?	459

Session 2: Environment and Social Issues **461**

<i>Artur M. C. Brito da Cruz, Helena Sofia Rodrigues and M. Teresa T. Monteiro</i> Household Costs for Personal Protective Measures for Dengue Disease	463
<i>Marek Kvet and Jaroslav Janáček</i> Incrementing Heuristic for Non-Dominated Designs of Emergency Medical System	469
<i>Teodora Mishevska and Samo Drobne</i> Functional Areas in Higher Education: A Case Study for Slovenia	475
<i>Mario Pepur</i> Validation of the Fan Type Scale in Croatia	481
<i>Lidija Zadnik Stirn and Gregor Dolinar</i> MCDM with Imprecise Information: Economic, Ecological, Social and Participatory Insights on Natural Resource Management Scenarios	487

Session 3: Finance and Investments **493**

<i>Zdravka Aljinović, Branka Marasović and Tea Kalinić Miličević</i> An Evidence on Risk and Return of Cryptocurrencies	495
<i>Frane Banić and Irena Palić</i> The Assessment of Twin Divergence in Croatia: The Impact of Trade Deficit on the Budget Deficit	501
<i>Boris Cota, Nataša Erjavec and Saša Jakšić</i> Income Inequality and Current Account Imbalances in New EU Members	507
<i>Aleš Kresta and Garegin Minasjan</i> Analysts' Recommendations as the Predictions of Future Stock Returns at Prague Stock Exchange	513
<i>Blanka Škrabić Perić and Ana Rimac Smiljanić</i> Derivatives Markets Development and Country Political Risk	519

Marija Vuković and Snježana Pivac
The Impact of Business Economics Students' Use of Heuristics on their Predispositions for Long-Term Investment Decisions 525

Session 4: Location and Transport, Graphs and their Applications **531**

Samo Drobne, Alberto Garre and Eloy Hontoria
Analysis of the Relationships between Slovenian Functional Regions Identified in the Network 533

Szilvia Erdős and Bence Kővári
Algorithms Based on Analytic Learning Neural Networks for Final Exam Scheduling 539

Elif Garajová and Miroslav Rada
Exact Method for the Worst Optimal Value of an Interval Transportation Problem 545

László Hajdu and Miklós Krész
The Influence Monitoring Problem 551

Tea Šestanović
Bitcoin Price Direction Forecasting Using Neural Networks 557

Session 5: Mathematical Programming and Optimization **563**

Valentina Đurek, Nikola Kadoić and Dijana Oreški
Effective Decision Making in Local Government Using the Hybrid Approach Based on Multi-Criteria Decision-Making Methods and Machine Learning 565

Milan Hladík
Six Ways how to Define Robust Pareto Optimality under Double Interval Uncertainty 571

Tibor Illés
Sufficient Matrices and Linear Complementarity Problems 577

Mira Krpan
Monopsony in Labor Market: Short-Run Profit Maximization Model from Duality Perspective 578

Zrinka Lukač
Optimal Taxation of a Monopoly with Cobb-Douglas Production Function for Two Inputs as a Bilevel Programming Problem 584

Tunjo Perić, Zoran Babić and Josip Matejaš
A New Methodology to Solve Decentralized Multi-Level Multi-Objective Linear Fractional Programming Problem 590

Session 6: Multi-Criteria Decision-Making **597**

Andrej Bregar
Multiple Criteria Utility Models for Sorting Incorporating Veto Related Preference Structures 599

Vesna Čančer
How to Create Piecewise Linear Value Functions 605

<i>Hannia Gonzalez-Urango, Rocío Poveda-Bautista, Pablo D'Este, Oscar Llopis and Adrian A. Diaz-Faes</i> A Multicriteria Approach for the Analysis of Biomedical Research Networks	611
<i>Petra Grošelj, Gregor Dolinar and Tjaša Šmidovnik</i> Comparison of Best-Worst Method and Analytic Hierarchy Process	617
<i>Rok Hržica and Mirjana Kljajić Borštnar</i> Multi-Criteria Decision Making Methods Comparison on a Case of Power Plant Procurement	623
<i>Jaroslav Janáček and Marek Kvet</i> Emergency Medical System under Conflicting Criteria	629
<i>Sabina Šegula, Vladislav Rajkovič and Uroš Rajkovič</i> Assessing Florists' Competencies Using Multicriteria Decision Methodology	636
<i>Andrej Škraba, Anja Žnidaršič, Davorin Kofjač and Alenka Baggia</i> Comparison of Student and Expert Idea Assessment in Online Brainstorming Session	642
<i>Tadeusz Trzaskalik</i> Vectors of Indicators in Multistage Bipolar Method	648
<i>Tomasz Wachowicz, Ewa Roszkowska, Krzysztof Piasecki and Marzena Filipowicz-Chomko</i> Analyzing the Concordance of Principals' Preference Representation by Agents with Different Decision-Making Profiles Using Generalized Fuzzy Approach	654

Session 7: Theory of Games **661**

<i>Jan Bok</i> Cooperative Interval Games and Selections Revisited	663
<i>Helena Gaspars-Wieloch</i> From the Interactive Programming to a New Decision Rule for Uncertain One-Criterion Problems	669
<i>Jakub Mróz and Tomasz Wachowicz</i> The Dyadic Analysis of the Impact of Conflict-Handling Style on Negotiation Outcomes in Software Supported Negotiations	675

Session 8: Problems Approaching OR **681**

<i>Nikola Kadoić, Dijana Oreški and Marija Lendl</i> Comparative Analysis of Decision Tree Methods from Two Scientific Fields	683
<i>Lorena Mihelač and Janez Povh</i> Computational Analysis of the Musical Diversity in 22 European Countries	691
<i>Dino Pavlic</i> Business Process Management and Customer Experience Management Convergence – A Literature Review	697

APPENDIX **705**

<i>Authors' addresses</i>	
<i>Sponsors' notices</i>	

Author index

A

Ágoston Kolos Csaba 49, 55
Aljinović Zdravka 255, 495
Alves Wellington 309, 333, 351
Andrić Gušavac Bisera 288

B

Babić Petra 136
Babić Zoran 590
Baggia Alenka 241, 247, 642
Ban Nikolina 3
Banić Frane 501
Bekavac Lidija 447
Benedek Márton 61
Berlec Tomaž 233
Besson Dominique 227
Bevanda Vanja 247
Bilka Matúš 255
Biró Péter 61, 62
Bogataj David 365, 389
Bogataj Marija 371
Bojković Nataša 294
Bok Jan 663
Bokal Drago 203, 221
Boršič Darja 429
Brečko Jure 397
Bregar Andrej 599
Brezavšček Alenka 262
Brito da Cruz Artur M. C. 463
Bulder L.N. 268

C

Castro Ana Rita 315
Chimani Markus 203
Chocholatá Michaela 435
Cota Boris 507
Cserssik Dávid 68
Cunjak Mataković Ivana 441
Czimmermann Peter 167

Č

Čančer Vesna 605
Čegovnik Tomaž 181

Ć

Ćukušić Maja 23
Ćurlin Tamara 209

D

Darvay Zsolt 83
Dávid Balázs 321
D'Este Pablo 611
Díaz-Faes Adrian A. 611
Dijk N.M. van 268
Dobrilović Kristina 288
Dobrovoljc Andrej 181
Dojčinović Aleksandar 215
Dolinar Gregor 487, 617
Drnovšek Rok 383
Drobne Samo 371, 475, 533
Druzsín Kristóf 62
Duarte Claudia 315
Dumičić Ksenija 441
Duraković Nataša 241

Đ

Đurek Valentina 565

E

E.-Nagy Marianna 49, 74, 75
Erdős Szilvia 539
Erjavec Nataša 507

F

Ferreira Ana Cristina 339
Ferenček Aljaž 101
Filipowicz-Chomko Marzena 654
Fleiner Rita 62
Frazão Nuno 327
Furková Andrea 435

G

Gabrovšek Boštjan 173
Gak Dragana 241
Garajová Elif 545
Garbin Praničević Daniela 17
Garcia Jorge Esparteiro 345, 351
Garre Alberto 533
Gaspars-Wieloch Helena 669
Gašperlin Blaž 107
Gonzalez-Urango Hannia 611
Grbić Tatjana 241
Grošelj Petra 617
Groznik Aleš 11
Gyetvai Márton 55

H

Hajdu László	551
Hegyháti Máté	321
Hell Marko	29
Hladík Milan	571
Hontoria Eloy	533
Hrga Timotej	188
Hribar Rok	194
Hržica Rok.....	623

I

Ignjatovic Marina	276
Illés Tibor	83, 85, 86, 577

J

Jadrić Mario	23
Jakšić Saša	507
Janáček Jaroslav	469, 629
Jelerčić Eva	11
Jerebic Janja	221, 241, 262
Jurić Ena	144
Jurun Elza	447
Juvančić Luka	404

K

Kadoić Nikola	565, 683
Kajzer Špela	221
Kalinić Miličević Tea	495
Kaloh Sarina	11
Kastrin Andrej	194
Kašparová Petra	113, 151
Kekez Ivan	17, 23
Kern Walter	61
Klimentova Xenia	62
Kljajić Borštinar Mirjana	101, 107, 623
Klun Maša	11
Kóczy László Á.	81
Kofjač Davorin	130, 642
Kojić Vedran	4
Kordić Lana	377
Kovács László	119
Kővári Bence	539
Koželj Romi	92
Kresta Aleš	513
Krész Miklós	551
Krpan Mira	578
Kušar Janez	233
Kvasina Antonija	29
Kvet Marek	469, 629

L

Lazarevic Ivana	276
Lendl Marija	683
Lichner Michal	167
Llopis Oscar	611
Logarušić Marija	459
Lopatič Maj	215
Lukač Zrinka	584

M

Madari Zoltán	125
Maksimović Aleksandar	410
Manfreda Anton	11
Marasović Branka	495
Maricic Milica	276
Marinović Minja	288
Matejaš Josip	590
Medić Slavica	241
Mihelač Lorena	691
Mijač Tea	29, 35
Milavec Kapun Marija	383
Miloloža Ivan	157, 209
Minasjan Garegin.....	513
Minović Jelena.....	282
Mishevska Teodora	475
Monteiro M. Teresa T.	463
Možanić Renata	389
Mrak Gregor	92
Mróz Jakub	675

N

Nascimento Joana	327
Nikolić Helena	209
Ninčević Pašalić Ivana	35
Novak Ana	404

O

Ognjenović Kosovka.....	453
Oliveira Lia Coelho de	345
Oreški Dijana	565, 683
Órfão Ana	333
Ősz Olivér	321

P

Packer do Amaral Vitoria	339
Palić Irena	501
Papa Gregor	194
Patrinos Panos	5
Paulusma Daniel	61
Pavlic Dino	697
Pavlovčič Prešeren Polona	41
Pažek Karmen	410
Pečar Martin	92
Pejić-Bach Mirjana	157
Peperko Aljoša	173
Pepur Mario	481
Perić Tunjo	590
Peršak Boris	130
Pervan Maja	136, 144
Piasecki Krzysztof	654
Pintado Eduardo	345
Pivac Snježana	525
Popović Milena.....	288
Poveda-Bautista Rocío	611
Povh Janez	181, 188, 194, 691
Prelog Martin	215
Prevolšek Boris	410, 422
Průcha Petr	113, 151
Pucihar Andreja	107
Puška Adis	410

R

Rada Miroslav	545
Rajkovič Uroš	130, 215, 241, 383, 636
Rajkovič Vladislav	383, 636
Ramos Bruna	339
Ratković Nada	447
Ribeiro Ana Cecília.....	327
Rigó Petra Renáta	83, 86
Rimac Smiljanić Ana	519
Rodrigues Cristina	227
Rodrigues Helena Sofia	309, 357, 463
Rogar Matic	181
Rogelj Valerija	365
Roszkowska Ewa	654
Rozman Črtomir	410, 422
Rudolf Janja	416
Rus Gregor	262

S

Savić Gordana.....	288
Sethi Suresh P.	6
Silva Ângela 309, 315, 333, 351, 357	
Silva Vieira Tiago Duarte.....	351
Solymosi Tamás	84
Sorić Petar	459
Sousa Ana	227
Szádoczkiné Varga Veronika	125
Sziklai Balázs R.	81

Š

Šegula Sabina	636
Šestanović Tea	557
Škraba Andrej	422, 642
Škrabić Perić Blanka	519
Šmidovnik Tjaša	617
Šušteršič Olga	383

T

Teixeira Senhorinha	227, 315, 327
Tollner Dávid	85
Tomat Luka	35
Török Roland	86
Tratnik Alenka	241
Trzaskalik Tadeusz	648

U

Udovč Andrej	416
--------------------	-----

V

Varga Anita	74, 75
Vasconcelos Ana Rita	357
Vegi Kalamar Alen	203
Višić Josipa	377
Vogrinc Monika	221
Vovk Maryna	247
Vuković Marija	525

W

Wachowicz Tomasz	654, 675
Werber Borut	247

Z

Zadnik Stirn Lidija	487
Zakonnik Lukasz	247
Zavrtanik Drglin Ajda	92
Zornić Nikola	294
Zoroja Jovana	157

Ž

Žerovnik Janez	173
Žgajnar Jaka	397
Žganec Gros Jerneja	7
Žibert Maja	410, 422
Živojinović Tanja	294
Žižek Lea	429
Žmuk Berislav	300
Žnidaršič Anja	241, 247, 262, 642
Žužek Tena	233