

Proceedings SOR

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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)

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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/>)

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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

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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
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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
Bíró 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
Csersik 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
García 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
Gyétvai 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 Uroš130, 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 Sofia309, 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
Szádóczkiné 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

SCHEDULING OF WASTE WOOD PROCESSING FACILITIES WITH OVERLAPPING JOBS

Balázs Dávid

InnoRenew CoE, 6310 Izola, Slovenia
University of Primorska, 6000 Koper, Slovenia
e-mail: balazs.david@innorenew.eu

Olivér Ósz

Department of Information Technology, Széchenyi István University, 9026 Győr, Hungary
e-mail: osz.oliver@sze.hu

Máté Hegyháti

Institute of Informatics and Mathematics, University of Sopron, 9400 Sopron, Hungary
e-mail: hegyhati.mate@uni-sopron.hu

Abstract: An important phase in most waste wood value chains is the processing of bulk waste from various sources, usually by means of shredding. This paper presents a method for scheduling the machines in such a waste wood processing facility, where incoming deliveries of different types of wood are processed by a series of treatment and transformation steps to produce shredded wood. A mathematical model is presented for the problem, that allows overlaps between consecutive steps to optimize resource flow through the system. The efficiency of the model is presented on randomly generated instances.

Keywords: scheduling, waste-wood processing, reverse wood value chain

1 INTRODUCTION AND MOTIVATION

The role of renewable materials and their reuse and recycling possibilities have become increasingly important with the growing significance of environmental awareness. One of the best examples for this is wood, a material that has a variety of primary uses, while also being a prime candidate for reuse and recycling. Optimization of the traditional product flows of wood is a well-researched area, with problems ranging from harvesting [14, 12] through facility-level decision-making (e.g. sawmilling [11], cutting pattern optimization [8]) to network-level modeling [13]. However, the utilization of waste wood and the reverse flows of this material are not widely studied. Waste wood can originate from a variety of sources, the two main groups being residual industrial wood (from the woodworking industry) and used wooden products (ranging from demolition waste to household items). However, similarly to other biomass residues, waste wood is mostly considered as a resource for energy production [15], and scientific studies usually concentrate on this aspect, while there might be more sustainable recycle possibilities [5].

As it was mentioned, the literature studying the optimization problems of waste wood is scarce. The two main research areas are the resource flow of waste wood for energy [6, 10] and the optimization problems of network design [2, 1, 16, 4]. While the previous studies concentrate mostly on network-level decisions, optimization problems in the nodes of waste wood logistics networks should also be studied. One important step is the processing of the collected waste, which is usually done by means of shredding, as most end-uses (e.g. energy or chipboard) require wood to be shredded to a certain size.

This paper presents the scheduling of a waste wood processing plant where the incoming wood deliveries are processed by a series of transformation steps in order to produce shredded wood. A mathematical model is formulated for the problem that allows overlapping of the automated processing steps in order to provide as continuous operation as possible. The efficiency of the proposed model is shown on instances that were randomly generated based on distributions from the literature. The presented model is a variation of our previously published work on scheduling waste wood processing facilities [3]. This previous study considered

the uncertainty of the type and origin of the incoming deliveries (which is not tackled in the current paper), it did not allow any overlapping between the various processes of the facility.

2 PROBLEM DESCRIPTION

The goal of the proposed approach is to minimize the total weighted lateness of a waste wood processing plant that processes deliveries from collection centers and households. Each delivery is considered to be a job that has to go through 5 processing steps:

- inspection and sorting (IS)
- metal separation (MS)
- coating removal (CR)
- shredding (SH) and reshredding (RS)
- screening (SC)

Shredding is the main step, which is carried out by dedicated, high-throughput machines. The shredded wood needs screening, which selects large pieces for reshredding. Screening has its dedicated machines, while reshredding is executed by the same machines as the shredding step.

For metal separation, two options are available. It can either be done manually by a dedicated crew or in an automated fashion by a magnetic separator after shredding. If metal separation is done manually, it has to precede coating removal, and succeed inspection, both carried out by their dedicated crew. Coating removal is only needed for a portion of the whole delivery.

The overall process of the plant is illustrated in Figure 1.

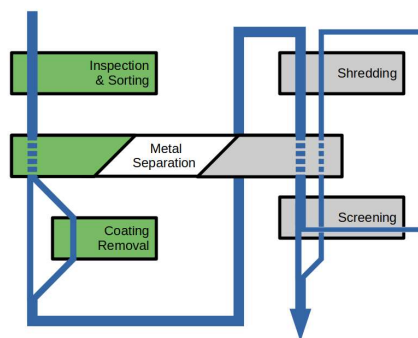


Figure 1: The possible flow of waste wood through the different transformation processes (green: manual steps, gray: machine steps).

The processing plant works in a semi-continuous fashion. Manual steps can be considered as batch subprocesses that cannot overlap or be interrupted. While the automated steps are also not interruptible, they can operate in a continuous way, so they may overlap with each other. Moreover, these steps may have an input storage/buffer that can hold shredded wood as long as needed, with sufficient capacity. Thus, fully batch operation is also available, if equipment availability would require it.

The re-entry of insufficiently shredded wood into the shredding machines forces the shredding step to envelop screening (and metal separation if done automatically) in time. Figure 2 illustrates the possible timings of these steps for both options with metal separation.

The dedicated crews for manual steps may not be split up between different jobs at the same time. However, several machines can be assigned to the same job simultaneously for the

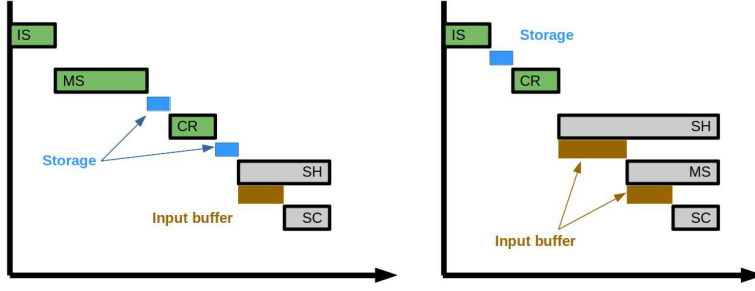


Figure 2: Possible timing of processing steps for both metal removal operations.

same step, if available. The percentage of wood / shredded wood that requires coating removal / reshredding can be estimated based on statistical data, based on the type of the delivery that can be either solid (S) or derived (D).

3 FORMAL PROBLEM DEFINITION AND THE PROPOSED MODEL

3.1 Problem data

The problem data is formally given as:

J is the finite set of jobs/deliveries.

$S = \{IS, MS, CR, SH, SC\}$ is the set of steps.

$d_j^a \in \mathbb{Z}^{0,+}$ is the day of arrival for the delivery of job $j \in J$. [day]

$d_j^s \in \mathbb{Z}^{0,+}$ is the day of shipping for the product of job $j \in J$. [day]

$p_j \in \mathbb{R}^{0,+}$ is the priority of job $j \in J$. [-]

$m_j \in \mathbb{R}^{0,+}$ is the total mass of the delivery of job $j \in J$. [t]

$t_j \in \{S, D\}$ is the type of job $j \in J$. [-]

M is the finite set of machines, partitioned to M^{IS} , M^{MS} , M^{CR} , M^{SH} , and M^{SC} .

$c_{mj} \in \mathbb{R}^{0,+}$ is the throughput capacity of a machine $m \in M$ for job $j \in J$. [t/h]

$s \in \mathbb{R}^{0,+}$ is the length of the shifts. [h]

$p_S^{CR}, p_D^{CR} \in [0, 1]$ are the percentages requiring coating removal and re-shredding for solid (S) and derived (D) deliveries. [-]

From the modeling point of view, dedicated crews behave exactly as machines, thus they are considered as such later on ($M^{IS} = \{IS\}$, $M^{CR} = \{CR\}$, and $MS \in M^{MS}$)

3.2 Variables

The proposed model relies on the following variables:

t_{js}^s, t_{js}^c non-negative continuous variables for starting and completion of step $s \in S$ for job $j \in J$.

a_{jm} binary variable that indicates if machine $m \in M$ is assigned to job $j \in J$.

q_{jm} non-negative continuous variable for the quantity of wood processed by machine $m \in M$ from job $j \in J$.

$b_{jsj'}$ binary variable that indicates if processing of job $j \in J$ precedes that of $j' \in J$ for step $s \in S$. ($j \neq j'$)

3.3 Constraints

Due to space limitations, only the key parts of the mathematical model are presented here. The constraints can broadly be categorized into three groups: logical/quantity constraints, recipe timing constraints and scheduling/sequencing constraints.

A key logical constraint forbids the assignment of any magnetic metal separator to a job if a crew already performed the task:

$$a_{jm} \leq 1 - a_{jMS} \quad \forall j \in J, m \in M \setminus \{MS\} \quad (1)$$

The total quantities assigned to the machines from a job must add up to the total mass of that job for each step. Depending on the step and the type of the job, this total mass may be different from m_j . The equation is the most complex for metal separation, as the total quantity is larger by the reshredded volume if automatic separation is selected:

$$\sum_{m \in M^{MS}} q_{jm} = m_j + m_j \cdot p_{t_j}^{RS} \cdot (1 - a_{jMS}) \quad \forall j \in J \quad (2)$$

These quantity variables can be used to provide a lower bound on processing times:

$$t_{js}^c \geq t_{js}^s + q_{jm}/c_{mj} \quad \forall j \in J, s \in S, m \in M^s \quad (3)$$

A group of recipe timing constraints set the starting and completion times for tasks of the same job. This constraint, for example, sets the timing appropriately between manual metal separation and coating removal:

$$t_{jCR}^s \geq t_{jMS}^c - \mathbf{M} \cdot (1 - a_{jMS}) \quad (4)$$

where \mathbf{M} is a sufficiently large number.

Sequencing of tasks assigned to the same unit are tackled with the following constraint:

$$t_{j's}^s \geq t_{js}^c - \mathbf{M} \cdot (3 - a_{jm} - a_{j'm} - b_{jmj'}) \quad \forall j, j' \in J, j \neq j', s \in S, m \in M^s \quad (5)$$

3.4 Objective

To calculate the objective, an integer helper variable l_j is introduced, which indicates the lateness. This variable is set by the following constraint:

$$t_{jSH}^c \leq (d_j^s + l_j) \cdot s \quad \forall j \in J \quad (6)$$

Then, the objective is simply expressed as:

$$\sum_{j \in J} l_j \cdot p_j \rightarrow \min \quad (7)$$

4 NUMERICAL RESULTS

As acquiring real-life datasets with varied sizes and structures is not a trivial task, testing of the model was done with the same methodology presented in [3]. Input instances were randomly generated based on available distribution data. The arrival day of the deliveries was chosen randomly over a one-week horizon for every instance. The features of the waste wood deliveries

were determined based on statistics in [7], their sizes were determined using the capacities of biomass transport trucks [9] and data on real machines was used to determine throughput.

Two different instance types were created: instances with small deliveries had a mass corresponding to the payload of a small truck (6 t–15 t) and the ones with large deliveries had a mass corresponding to the payload of an average-sized biomass transport truck (31 t–49 t). The number of deliveries was a multiple of five between 5 and 30 for each instance. This resulted in 12 instance sets (one for each each pair of delivery size and delivery number, e.g. '25 large deliveries'), with 20 different random instances in each set. The model was solved for all instances using the Gurobi 9.1 solver on a PC with an Intel Core i7-5820K 3.30 GHz CPU and 32 GB RAM. A running time limit of 1800 s was introduced to all test runs.

Instances with 30 or fewer small deliveries were all solved to optimality in less than 1 s. The model was also tested for instances with 35 and 40 small deliveries, but these did not yield optimal solutions in the given time limit.

Instances with large deliveries were solvable to optimality in the case of 15 or fewer deliveries. Only half of the 20-delivery instances yielded optimal solutions within the time limit, while the suboptimal results of the remaining 10 instances had an average gap of 44.33%. A significant number of the larger instances did not provide solutions within the time limit: only 9 and 13 instances were optimal in the case of the 25- and 30-delivery sets respectively. For the remaining instances, there were either no feasible solutions found within the time limit, or only ones with extremely large optimality gaps.

5 CONCLUSIONS

This paper presented the problem of machine scheduling in a waste wood processing plant where the incoming deliveries of wood are shredded. A mixed-integer linear programming model was presented for the problem that allows overlapping of the machine processing steps so the flow of material can be as continuous throughout the facility as possible. The efficiency of the model was shown on instances that were randomly generated based on real-life statistical data. Results showed that the model is capable of scheduling a large amount of jobs over the short-term period of one week, under a short solution time. Possible extensions of this work can include an exhaustive testing of larger planning periods of several weeks, as well as the development of metaheuristic algorithms for solving instances with even larger number of deliveries. The proposed model should also be tested for real-world datasets.

Acknowledgements

This research was supported by the National Research, Development and Innovation Office, NKFIH grant no. 129178. Balázs Dávid gratefully acknowledges 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). He is also grateful for the support of Slovenian ARRS grants N1-0093 and BI-AT/20-21-014. The Authors would like to acknowledge the work of Szabolcs Dávid, who was helping the research with testing the developed method. He was supported by “Integrated program for training new generation of scientists in the fields of computer science”, no. EFOP-3.6.3-VEKOP-16-2017-0002 (supported by the European Union and co-funded by the European Social Fund).

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