Impressum

Focus and Scope

Business Systems Research Journal (BSR) is an international scientific journal focused on improving the competitiveness of businesses and economic systems. BSR examines a wide variety of decisions, processes, and activities within the actual business setting and the systems approach framework. Theoretical and empirical advances in business systems research are evaluated regularly. Special attention is paid to educational, social, legal and managerial aspects of business systems research. In this respect, the BSR journal fosters the exchange of ideas, experience, and knowledge between regions with different technological and cultural traditions, in particular in transition countries.

Papers submitted for publication should be original theoretical and practical papers. The journal also publishes case studies describing innovative applications and critical reviews of theory.

Abstracted/indexed in:
Cabell's Directory, Clarivate Analytics’ The Emerging Sources Citation Index (ESCI) Web of Science, CEJSH (The Central European Journal of Social Sciences and Humanities), Celdes, CNKI Scholar (China National Knowledge Infrastructure), CNPIEC, DOAJ, EBSCO - Business Source, ERIH PLUS (European Reference Index for the Humanities and Social Sciences), Google Scholar, Hrcak, Inspec, J-Gate, JournalTOCs, Naviga (Softweco), Primo Central (ExLibris), ProQuest (relevant databases), ReadCube, Research Papers in Economics (RePEc), Summon (Serials Solutions/ProQuest), TDM (TDNet), TEMA Technik und Management, Ulrich's Periodicals Directory/ulrichsweb, WorldCat (OCLC)

Editor-in-Chief
Mirjana Pejić Bach, University of Zagreb, Faculty of Economics & Business, Department of Informatics, Croatia

Associate Editors
João Varajão, Universidade do Minho, Portugal
Josip Stepanić, University of Zagreb, Faculty of Mechanical Engineering and Naval Architecture, Department of Non-destructive Testing, Croatia
Nataša Šarlija, University of Osijek, Faculty of Economics in Osijek, Croatia, Croatia

Advisory Board
Sarunas Abramavicius, ISM University of Management and Economics, Lithuania
David Al-Dabass, Nottingham Trent University, School of Computing & Informatics, United Kingdom
Jakov Crnkovic, University at Albany, School of Business, USA
Martin Fieder, University of Vienna, Rector’s Office, Austria
Anita Lee Post, University of Kentucky, School of Management, Decision Science and Information Systems Area, United States
Gyula Mester, University of Szeged, Hungary
Matijaž Mulej, International Academy of Cybernetics and Systems, Austria, University of Maribor and IRDO Institute for development of social responsibility, Slovenia
Olivia Par-Rudd, OLIVIAGroup, United States
Ada Scupola, Department of Communication, Business and Information Technologies, Roskilde University, Denmark
Tadas Šarapovas, ISM University of Management and Economics, Lithuania
Ajay Vinze, Arizona State University, WP Carey School of Business, United States
Editorial Board

Nahed A. Azab, School of Business, American University in Cairo, Egypt
Sheryl Buckley, University of South Africa, School of Computing, South Africa
Terence Clifford-Amos, Université Catholique de Lille, France
Josef Basl, University of Economics, Prague, Czech Republic
Nijaz Bajgorić, University of Sarajevo, School of Economics and Business, Bosnia and Herzegovina
Rajeev Dwivedi, Institute of Management Technology, India
Inês Dutra, Universidade do Porto, Portugal
Francisco García, Universidad de Salamanca, Spain
B. B. Gupta, National Institute of Technology Kurukshetra, India
Mojca Indihar Štemberger, Faculty of Economics, University of Ljubljana, Slovenia
Božidar Jaković, University of Zagreb, Faculty of Economics & Business, Department of Informatics, Croatia
Mira Krpan, University of Zagreb, Faculty of Economics & Business, Department of Economic Theory, Croatia
Helmut Leitner, Graz University of Technology, Institute for Information Systems and Computer Media (IICM), Austria
Sonja Sibila Lebe, Faculty of Economics and Business, Maribor, Slovenia
In Lee, School of Computer Sciences, Western Illinois University, USA
Olivera Marjanović, University of Sydney, Faculty of Economics & Business, Department of Business Information Systems, Australia
Irena Palić, University of Zagreb, Faculty of Economics & Business, Department of Statistics, Croatia
Sanja Pekovic, University Paris-Dauphine, France
Lei Ping, Shanghai University of International Business and Economics, China
Markus Schatten, University of Zagreb, Faculty of Organization and Informatics, Croatia
Vanja Šimičević, University of Zagreb, Croatian Studies, Department of Sociology, Croatia
Nikola Vlahović, University of Zagreb, Faculty of Economics & Business, Department of Informatics, Croatia
Ilko Vrankić, University of Zagreb, Faculty of Economics & Business - Zagreb, Croatia, Croatia
Zhang Wei-Bin, Ritsumeikan Asia Pacific University, Japan
Berislav Žmuk, University of Zagreb, Faculty of Economics & Business, Department of Statistics, Croatia

Language Editors

Abstract Editing: Andrea-Beata Jelić, Poliglossa Language Centre, Croatia

Managing Editors

Ljubica Milanović Glavan, University of Zagreb, Faculty of Economics & Business, Croatia
Jasmina Pivar, University of Zagreb, Faculty of Economics & Business, Croatia
Mihovil Braim, University of Zagreb, Faculty of Economics & Business, Croatia, Student Assistant

Publisher

IRENET, Society for Advancing Innovation and Research in Economy

ISSN

Business systems research (Online) = ISSN 1847-9375

Editorial Office

e-mail: bsreditors@gmail.com
Web:
Business Systems Research
A Systems View across Technology & Economics

Special Issue
“Novel Solutions or Novel Approaches in Operational Research”
co-published with the Slovenian Society INFORMATIKA – Section for Operational Research (SDI-SOR)

Guest Editors
Samo Drobne, Ksenija Dumičić and Lidija Zadnik Stirn

Editorial

Novel Solutions or Novel Approaches in Operational Research
Samo Drobne, Ksenija Dumičić, Lidija Zadnik Stirn

Research Articles

Green Practices as a Path towards the Sustainability: Evidence from Portuguese Companies
Wellington Alves, Ângela Silva, Helena Sofia Rodrigues

Comparison of Two Network-Theory-Based Methods for detecting Functional Regions
Samo Drobne, Alberto Garre, Eloy Hontoria, Miha Konjar

Deep Learning Predictive Models for Terminal Call Rate Prediction during the Warranty Period
Aljaž Ferencek, Davorin Kofjač, Andrej Škraba, Blaž Sašek, Mirjana Kljajić Borštnar

Process Mining Contributions to Discrete-event Simulation Modelling
Mario Jadrič, Ivana Ninčević Pašalić, Maja Ćukušić

Portfoliо Optimization Efficiency Test Considering Data Snooping Bias
Aleš Kresta, Anlan Wang

Improving Mental Wellbeing in Organizations with Targeted Psychosocial Interventions
Dean Lipovac, László Hajdu, Sølvi Wie, Anders Q. Nyrud

Selection of Project Managers: An Overview
Marija Šiško Kuliš

Pension Pessimism in the Young Generation: Basics or Instincts to Blame?
Erzsébet Kovács, Ágnes Vaskővi
A System Dynamics Approach to Decision-making Tools in Farm Tourism Development
Maja Žibert, Črtomir Rozman, Andrej Škraba, Boris Prevolšek

Standard Project Risk Analysis Approach
Tena Žužek, Lidiija Rihar, Tomaž Berlec, Janez Kušar

An Investigation of Business Process Maturity: Report on Croatian Companies
Ljubica Milanović Glavan

132
149
159
Editorial for the special issue: “Novel Solutions and Novel Approaches in Operational Research”
co-published with the Slovenian Society INFORMATIKA – Section for Operational Research (SSI-SOR)

Samo Drobne
University of Ljubljana, Faculty of Civic and Geodetic Engineering, Ljubljana, Slovenia
Ksenija Dumičić
University of Zagreb, Faculty of Economics and Business, Zagreb, Croatia
Lidija Zadnik Stirn
University of Ljubljana, Biotechnical Faculty, Ljubljana, Slovenia

Abstract
This special issue of Business Systems Research (SI of the BSR) is co-published by the Slovenian Society INFORMATIKA – Section for Operational Research (SSI -SOR) and highlights recent advances in Operations Research and Management Science (OR /MS), with a focus on linking OR /MS with other areas of quantitative and qualitative methods in a multidisciplinary framework. Eleven papers selected for this SI of the BSR present improvements and new techniques (methodology) in Operations Research (OR) and their application in various fields of economics, business, spatial science, smart mobility, higher education, human resources, environment, agriculture and social networks.

Keywords: interdisciplinary research, operations research, risk and uncertainty, statistical analysis, machine learning, multi-criteria decision making, big data, location-allocation, fuzzy logic, graph theory, project management, system dynamics, simulation methods.


Editorial process
The term operations research (OR), or often management science (MS), refers to a scientific approach to decision making that attempts to determine how best to design or operate a system, usually under conditions that require the allocation of resources in business language (Winston, 2003). OR is a decision support discipline and as such is concerned with the development of systems to help decision makers to solve problems and make decisions. Within decision support topics, OR offers data analysis, simulation, modelling techniques, and software tools (Mladenić et al., 2003; Rubio et al., 2014).

The applications of OR in real word problems are very numerous and in very different fields such as industrial engineering, management, economics, production, government, health care, transport, geographic information systems, scheduling, marketing, inventory, environment and others (Cochran et al., 2011). The applications of OR allow complex
problems to be structured transparently and flexibly in a realistic context, introducing both quantitative (e.g. financial ratios) and quantitative criteria into the evaluation process (Figueira et al., 2005).

OR has had an important impact on improving the efficiency of organizations and has contributed to increasing productivity and social welfare. The International Federation of Operational Research Societies (IFORS) and the Association of European Operational Research Societies (EURO) are umbrella organizations for OR societies worldwide, representing more than 50 national societies, including Slovenian Society INFORMATIKA - Section for Operational Research (SSI-SOR). The main events organized by SSI-SOR are the international symposia. The 15th International Symposium on Operations Research, called SOR’19, took place in Bled, Slovenia, from 25 to 27 September 2019. SOR’19 was the scientific event in the field of Operations Research, another in the traditional series of biennial international OR conferences, organized in Slovenia by SSI -SOR. The main objective of SOR’19 was to promote the knowledge, interest and education of OR in Slovenia, in Europe and worldwide, in order to build the intellectual and social capital that is essential for maintaining the identity of OR, especially in a time when interdisciplinary cooperation is proclaimed to be significantly important for solving problems in the current challenging times. Furthermore, the SSI -SOR agreed to cooperate with different disciplines, i.e. to strike a balance between the depth of theoretical knowledge in OR and the understanding of theory, methods and problems in other areas inside and outside OR. About 115 participants from research institutes, universities, governmental institutions, private and public companies from 16 countries around the world took part in SOR’19. 106 papers were presented, written by 203 authors and co-authors. The papers were accepted after a blind peer review process by two independent reviewers selected from SOR’19 Program Committee and by reviewers appointed by SSI -SOR.

At SOR’19 it was agreed that the special issue (SI) of the BSR would be published, so the Call for Papers for this SI was already published during this symposium in Bled in September 2019. The call was addressed to the participants of SOR’19 as well as to other researchers from the area of OR. The submitted papers should present developments and new techniques in OR methods/models and their practical applications in the fields of economics, business, finance, organization, management, social sciences, environment, transport and other fields.

Several contributions have been received. Some of them are extended journal versions of short SOR’19 papers from proceedings (Zadnik Stirn et al., 2019). Each submission to the SI of the BSR was first blind reviewed by the guest editors and then by two independent experts. Eleven contributions were selected for this special issue of the BSR. They owe their practical orientation and the consistent emphasis on model formulation and modelling. In addition, they go beyond a mere presentation of algorithms and reinforce the features and coverage of the latest developments in optimization, simulation and decision analysis.

The selected contributions deal with developments and techniques in OR and their practical application in the fields of business, economics, spatial science and location, environment and social sciences. The topics covered in the selected contributions represent interdisciplinary research and include, from a methodological point of view, multi-criteria decision making, fuzzy logic, neural networks, machine learning, predictive models, risk and uncertainty, and big data, while from an application perspective, they include business process modelling, organisational performance, strategic planning, financial applications, farm tourism, project management, pension expectations, mental wellbeing of employees, smart mobility, and higher education. The case studies origin from five countries: Portugal, Croatia, Slovenia, Norway and Hungary.
The success of the SI of the BSR should be seen as a result of the joint efforts. The guest editors would like to thank the authors for their well-written contributions and the reviewers for their careful evaluation of the submissions and their thoughtful and constructive comments. Last but not least, the guest editors express their deep appreciation and gratitude to the editor-in-chief, Professor Mirjana Pejić Bach, PhD for her generosity, service and commitment in inviting us as guest editors of SI of the BSR.

Contributions
In accordance with the goals and editorial policy of BSR, the papers published in BSR are intended to present original theoretical and empirical advances in business and economic systems using a wide range of methodological approaches, primarily from the fields of operations research/ analytics, management science and statistics. The eleven papers accepted by BSR for this SI fulfil these objectives.

In the first paper, entitled “Green Practices as a Path towards the Sustainability: Evidence from Portuguese Companies”, Alves, Silva and Rodrigues consider the problem of the impact the companies cause on the environment and the society. They evaluate the level of environmental practices in micro, small, medium and large companies in the northern region of Portugal. The results reveal that the environmental issues are not yet properly addressed by treated companies; especially small companies face several barriers to implement green actions, mainly those related to certification. The value of the paper is its contribution to new insights on how the handled companies have been implementing sustainable practices, as well which practices they still need to develop to reach higher level of strategic, including financial, policies, and green and sustainable practices.

In the second paper, entitled “Comparison of Two Network-Theory-Based Methods for detecting Functional Regions”, authors Drobne, Garre, Hontoria and Konjar analyse two methods for modelling functional regions based on graph theory. In the case study of Slovenia, functional regions are calculated using the Walktrap algorithm and a proprietary, so-called, chain approach. They analyse the quality of the two regionalisation methods using the fuzzy set theory with its revised approach. After the results of the case study of Slovenia, the authors concluded that the Walktrap algorithm functionally calculates more closed regions (more workers find work in the home region) than their chain method.

In the third paper, entitled “Deep Learning Predictive Models for Terminal Call Rate Prediction during the Warranty Period”, Ferencek, Kofjač, Škraba, Sašek and Kljajić Borštnar present the problem of production companies to optimize their costs by minimizing the amount of funds to be reserved for product repairs during the warranty period. The research extends previous research by providing new insight into machine learning models, and offers additional understanding and validation on how data quality can affect those models. A few new predictive models based on different neural network architectures were developed. They were implemented on a case of a company in the field of home appliances. The results show that the best two models, deep neural network with 6 layers and a convolutional neural network differed in 1% when predicting products’ terminal call rate at 12 months.

In the next paper, entitled “Process Mining Contributions to Discrete-event Simulation Modelling”, Jadrić, Ninčević Pašalić and Ćukušić state that the technological advance supported by information systems generates event logs which contain important information about the performance of a business process. Event logs are analysed using process mining techniques. The aim of the paper is to demonstrate and assess the potential of using process mining results as an input for discrete-event simulation modelling. The process mining procedure is employed on two datasets. The results show
that process mining coupled with simulation models offers a suitable innovation environment. Practical implications in the smart parking case refer to better use of (public) resources, and point to the constraints in terms of the non-existence of specific event data, while in the case of higher education the results indicate a better prediction of student behaviour.

In the fifth paper, entitled “Portfolio Optimization Efficiency Test Considering Data Snooping Bias”, Kresta and Wang are interested in the evaluation of strategy portfolio performance. The general approach for such evaluation is testing whether the strategy outperforms the benchmark. Such approach does not answer whether the overperformance is high enough to be considered as significant or whether it is just due to the randomness in data. Consequently, the authors propose an alternative approach based on the statistical test in order to evaluate the efficiency of the portfolio optimization strategies in view of the risk. The proposed approach is demonstrated on the Markowitz minimum variance model and the fuzzy probabilities minimum variance model. The results confirm that minimizing the variance of portfolio return in-sample also lowers the out-of-sample risk measures, and that the analysed strategies lower the risk of the portfolio during the market’s decline in 94% of the time in the 2009–2019 period.

Examining the mental wellbeing of employees, which is crucial for the long-term success of an organization, the authors Lipovac, Hajdu, Wie and Nyrud offer to the readers the sixth paper, entitled “Improving Mental Wellbeing in Organizations with Targeted Psychosocial Interventions. The presented research is looked at within individual-level interventions approach. The authors created a social network based on the data collected on 414 employees from 14 nursing homes in Norway where the nodes represent employees and edges describe the connections between the nodes, while the edge probability represents the connection strength between two nodes. The optimization environment computes the possible intervention scenarios and maximizes the overall wellbeing by minimizing the scores of the nodes (i.e., reversed wellbeing score) with the set of employees receiving the intervention. Interventions were provided to either contagious or randomly selected individuals. The results show that selectively targeting highly contagious individuals could be an efficient approach to improving wellbeing in organizations.

In the seventh paper, entitled “Selection of Project Managers: An Overview”, the author Šiško Kulish presents the problem of selecting a project manager. The paper is seen as an overview paper focusing on the existing studies/methodology. Project manager selection is concentrated on two approaches, a traditional one and on a modern based on multi-criteria decision making. The traditional approach is supported by structured interviews with the goal to project the candidate’s behaviour in new and unknown circumstances. A new, modern, approach is based on psychometric testing and multi-criteria methods, among which AHP has an important place. Current characteristics of the process of selecting project manager in Croatia are investigated. A special attention is devoted to the certification of managers as certificate is the basic criteria during project manager selection process. Important for the future research in the field is also the enormous list of up-to-date references.

Then follows the paper entitled “Pension Pessimism in the Young Generation: Basics or Instincts to Blame?”, written by Kovács and Vaskóvi, which is dealing with pension expectations that are so important for national economies, decision makers and individuals. The paper focuses Hungarian young generation’s reasons regarding pessimistic attitude towards state pension expectations. A non-representative sample research is applied, resulting with 250 filled questionnaires. The surveys data were analysed using multidimensional statistical method, above all factor analysis, to test different hypotheses connected to financial literacy and gender differences in the
pension scheme. The survey results were used also to make a comparative analysis with the ten biases, called instincts by Rosling (2018), in order to find the behavioural aspects lying behind the pessimistic attitude of most respondents. The overall results reveal general pessimism among Hungarian university students towards the social security benefits, due to the general pessimism in the ‘overdramatic worldview’.

Further, the paper, entitled “A System Dynamics Approach to Decision-making Tools in Farm Tourism Development”, Žibert, Rozman, Škraba and Prevolšek, establish that nowadays more and more agricultural holdings decide on developing market-oriented multi-function farming. The focus of their research is the development of rural tourism as one of socio-economic activities. The authors generate a qualitative causal loop model and a system dynamics model for the simulation of transition of farming establishments into tourist farms for the purpose of increasing income through the diversification. The validation of the model was upgraded with the Mean Squared Error auxiliary variable and Cumulative Mean Squared Error level element, using Powersim Solver with Genetic Algorithms. Different parameter values were used in eight simulation scenarios. The case study of Slovenia has been used in order to explore the scenarios for farm tourism development. It was discovered that transition to diverse farms relies on subsidies that are the main driving force for the transition.

In the tenth paper, entitled “Standard Project Risk Analysis Approach”, Žužek, Rihar, Berlec and Kušar, state that the companies, if they want to stay effective, have to be able to adapt to the competitive environment and to essentially manage the risk. The authors consider different risk analysis methods/tools: qualitative, semi-quantitative, quantitative and a risk matrix which is in the quantitative case extended into a continuous graph, called a risk map. First, the major risk factors were identified and assigned to individual activities. The risk events were linked to their impacts, and the risk event probabilities, based on the experience with similar projects, were assessed. Finally, a risk map was generated. The results show that separate treatment of the risk event and the impact advantageous clarifies the cause and the effect, and thus allows for a separate planning of preventive and corrective measures.

In the last paper of this SI, entitled “An Investigation of Business Process Maturity: Report on Croatian Companies”, Milanović Glavan, considers business process maturity which is an extensive version of business process orientation (BPO). Reaching higher stages of maturity means higher levels of process skills for the company while companies are viewed as a mixture of unified business processes. In every maturity level, it is of crucial importance to recognize and improve key turning points, i.e., maturity components that lead companies to the next level. The aim of the research was to provide a report on BPO maturity of Croatian companies and to stress the importance of key turning points. The level of maturity was investigated, the turning points were addressed by using cluster analysis method, and finally the most critical maturity components for each maturity level were determined. The results of the cluster analysis show that companies in Croatia have to improve all key turning points, with a special emphasis on the strategic view.

It might be concluded that the high quality and up-to-date challenging topics of the SI of BSR papers would be interesting to both, the scientific and the professional audience, since possible influence on theory and applications are visible.

Ljubljana, Zagreb, October 2020

Guest Editors of SI BSR

Samo Drobne
Ksenija Dumičić
Lidija Žadnik Stirn
References

About the editors

Samo Drobne
Member of Management Board of Slovenian Society INFORMATIKA – Section for Operational Research (SSI-SOR); Secretary of Slovenian Society INFORMATIKA – Section for Operational Research (SSI-SOR); Co-editor of several proceedings of the international symposia on operations research in Slovenia (Proceedings of SOR); Member of Editorial board of Geodetski vestnik – an open access journal of the Association of Surveyors of Slovenia; Member of Editorial board of Journal Communications - Scientific Letters of the University of Žilina. Editor can be contacted at samo.drobne@fgg.uni-lj.si

Ksenija Dumičić
Elected Member of International Statistical Institute (ISI) and Member of ISI Sections: International Association of Survey Statisticians (IASS) and International Association of Statistical Education (IASE); Member of: Royal Statistical Society (RSS), American Statistical Association (ASA), American Society for Quality (ASQ) and ASQ Statistics Division, Croatian Operational Research Society (CRORS) and Croatian Biometric Society (HBMD); Chair of Women in Statistics Section at Croatian Statistical Association (CSA); Management Committee Member of ISI Committee on Women in Statistics (CW-ISI); Editorial Board Member of: Croatian Operational Research Review (CRORR), Croatian Review of Economic, Business and Social Statistics (CREBSS) and Proceedings of the Faculty of Economics and Business in Zagreb; Program Committee Member of International Symposium on Operations Research in Slovenia - SOR, Slovenia. Editor can be contacted at kdumicic@net.efzg.hr

Lidija Zadnik Stirn
President of Slovenian Society INFORMATIKA – Section for Operational Research (SSI-SOR); Vice-president of Slovenian Society INFORMATIKA (SSI); Representative of SSI-SOR in International Federation of Operational Research Societies (IFORS); Representative of SSI-SOR in Association of European Operational Research Societies (EURO); Co-editor of Central European Journal of Operations Research (CEJOR); Co-editor of several proceedings of the international symposia on operations research in Slovenia (Proceedings of SOR); Member of Editorial board of Croatian Operational Research Review (CrORR). Editor can be contacted at lidija.zadnik@bf.uni-lj.si
Green Practices as a Path towards the Sustainability: Evidence from Portuguese Companies

Wellington Alves
Escola Superior de Ciências Empresariais, Instituto Politécnico de Viana do Castelo; ALGORITMI Research Centre, University of Minho; Escola de Engenharia, Depto Produção e Sistemas, Campus de Azurém, Portugal

Ângela Silva
Escola Superior de Ciências Empresariais, Instituto Politécnico de Viana do Castelo; Centro de Investigação em Organizações, Mercados e Gestão Industrial (COMEGI), Lusíada University, Portugal

Helena Sofia Rodrigues
Escola Superior de Ciências Empresariais, Instituto Politécnico de Viana do Castelo; Center for Research and Development in Mathematics and Applications (CIDMA), University of Aveiro, Portugal

Abstract

Background: In the last years, the concept of sustainability has been receiving global attention from academics, the public sector and practitioners. The high level of industrialization has contributed to the increase of environmental impacts on the environment and the society. To give a sustainable answer to the industrial sector, more strategies aimed at reducing the environmental and social impacts should be considered. Objectives: This research aims to evaluate the level of environmental practices in a set of companies from the northern region of Portugal. Methods/Approach: In order to achieve the objective of this research, several steps were taken, and approach is mainly based on an online questionnaire administered in a set of companies. Results: The initial results show that companies are progressing when it comes to the implementation of measures and practices related to sustainability. Conclusions: The study resulted in suggestions for consulted companies, namely the need for effective mechanics to ensure compulsory but expedite environmental procedures along with procedures control, which is a key factor in ensuring sustainable and green practices.

Keywords: green practices, sustainability, Portugal, statistical analysis

JEL: L16

Paper type: Case Study

Received: Jan 30, 2020
Accepted: Jul 6, 2020


DOI: 10.2478/bsrj-2020-0012
Introduction
At the heart of sustainable development, is the need to build-up initiatives, measures, assessment and monitoring production processes that may cause environmental, social and economic impacts on society. The contribution to the reduction of these impacts could increase the prominence of sustainability in the industrial sector (Khandokar et al., 2009).

Over the last decade, the concept of sustainability has been receiving global attention from academics, public sector and practitioners. Yet, the industrial sector has a long path to go on achieving sustainable process in their industrial processes (Varela et al., 2019). In response to the urgent for sustainability, strategies for environmental and social impacts must be considered. According to OECD (2010, p.4) sustainable strategies are usually based “on the identification and evaluation of criteria that expose potential impacts on the three dimensions of sustainable development, namely, social, economic and environmental”. Towards sustainability, sustainable practices have been increasing attention as a powerful driver to achieve sustainable development. These practices are related to the development of initiatives and policies to guide companies to improvements in their operations. Despite the relevance of the integration of sustainable practices into traditional operations to increase sustainable performance, it is still a barrier for small and medium-sized companies.

It is the case of Portugal, the country is characterized by a large amount of micro, small and medium enterprises (SMEs). Over the last years these companies have increasing awareness of the needs to implementation of sustainable strategies. However, there are still many SMEs which lack resources and capabilities or suffer from inertia in this field, it has been contributing to discourages the intentions to develop sustainable practices. The case of companies operating in the Northern region of Portugal is particularly relevant since studies showing (see Pereira & Leitão, 2013; European Commission, 2020) that small-scale companies operating is a major issue in the region (PORDATA, 2020). Despite the contribution of these companies for the region, the implementation of sustainable practices persists as a challenge task for these companies (Moreiras, 2010).

Connecting company's activities to their environmental, social and economic impacts, rise the need to create sustainable strategies to decrease its impacts. This paper aims then to answer the following question: Which environmental practices have been adopted by companies operating in the northern region of Portugal? Then, the research aims to analyze the implementation level of practices related to environment in a set of companies from the North of Portugal.

To accomplish the objective of the study, it has conducted a review of the relevant literature relevant to sustainability and environmental practices. Then, the case of companies operating in the Northern region of Portugal was taken as a sample. In summary, taking into consideration that researches addressing sustainable practices in SMEs in the Northern region of Portugal have not been addressed, this paper aims to contribute to new insights on how these companies have been implementing sustainable practices towards sustainability, as well which practices are already implemented.

The paper is organized into five main sections. Pertinent literature focusing on the relevance of the research, discussing sustainability and environmental practices was conducted in Section 2. Then, the research design and methodology chosen are presented in order to assess the environmental management practices in the North of Portugal, in Section 3. Section 4 presents and discusses the main results; highlighting aspects such as enterprise category (micro, small, medium or large) environmental
policies were analysed. Section 5 presents conclusions and identifies directions for future works. The paper has been presented at SOR 2019 conference (Silva et al., 2019).

**Literature overview**

As one of the key documents within the scope of sustainability the Bruntland Commission Report defines sustainable development as the capability of the present-day generations to meet their needs without compromising the capacity of the forthcoming generation achieving their needs (World Commission on Environment and Development, 1987). The discussion around sustainability are mainly integrated within companies that already perceived sustainability as important aspects to be taken into account ias a strategy to improve performance (Alves et al., 2018).

In the last few years, sustainability has been seen as a key subject for organizations worldwide; it has been supporting industries towards addressing economic, social and environmental strategies int their production processes, towards sustainable practices (Ching et al., 2014).

Yet, environmental practices have been posted as a key driver for organizations to the development of sustainability. For instance, a work developed by Rashidi and Cullinane (2019) has investigated the role of sustainability on improving operational logistics performance of companies from different countries. Also, Dey et al. (2011) investigated the development of initiatives towards sustainability in the field of supply chain operations, the work identified opportunities for companies regarding the accomplishment of sustainable practices in logistics.

In this context, due to the complexity of supply chains, sustainability has been jumped in the green agenda for all industrial sectors. The need for incorporating sustainable practices focusing on, for instance, the reduction, or even elimination of the negative impacts generated by products and operational processes on the environment has become imperative for all companies worldwide (Bahr and Sweeney, 2019).

The synergy between green practices and sustainability has been driving forces to implementation of sustainable practices in several industrial sectors. The implementation of these initiatives has the potential to increase sustainable results in industries (Dües et al., 2013). According to Thorlakson et al. (2018) global supply chain plays a critical role in pressing environmental, social and economic stress struggles identified by the United Nations’ Sustainable Development Goals (SDGs). The 17 Sustainable Development Goals (SDG) developed by the United Nations, which aims at fostering global sustainable development through economic, environmental and social level, also established that there is a need for call attention of supply chains to develop sustainable practices, it due to its considerable influence on sustainable development (Thorlakson et al., 2018; Brockhaus et al., 2019). Yet, environmental and social impacts, such as increasing exhaustion of resources, environmental pollution and global warming are increasing the concerns of government, communities and companies to develop actions towards reductions of ecological and social problems (Yildiz Çankaya & Sezen, 2019).

Responding to calls from the global community, industries have been paid to the environmental impacts originated from their processes and products. Yet, over the last decades, the connection between sustainable development and green business, has gained increasing importance in the literature in the last years. Nonetheless, the dialogue about environmental strategies in small-medium size industrial activities has not yet gained ground. For instance, the work developed by Aldakhil et al., (2018) examines the key determinants of integrated supply chain management for green business growth for BRICS countries (Brazil, Russia, India, and China), considering some
aspects such as economic growth and environmental policies, the worked showed that those companies (small-medium size industrial) face several challenges, such as lack of qualified works and financial support when implementing environmental practices.

According to Sharma (2016) green practices serve as a springboard to develop environmental initiatives towards sustainability, also to contribute to competitive advantage for the industrial sector. The authors defend that sustainability has been one of the most important issues for the manufacturing and development of new products. The reduction of environmental impact has been considered as one of the key principle for governments and society (Alves, et al., 2018). It has led companies to go green and reduce the environmental effect caused by its operations, as well meeting sustainability principles (Bathmanathan & Hironaka, 2016).

As the resources depletion has taken place in the agenda of the modern societies, to meet the society needs but at the same time to minimize the environmental and social impact caused by the industrial sector, it is imperative to companies develop initiatives focusing on green and eco-friendly strategies (Pradeep & Kuckian, 2017). Due to the possibility to support companies to address environmentally friendly strategies on producing goods and services, green initiatives have been increasing attention within industrial sector. According to Bathmanathan and Hironaka (2016), the use of green practices such as environmental management, development of eco-friendly products, implementation of environment policy and implementation of certification ISO 14001, are some examples of practices which have been supporting companies to shift their business, towards the sustainable agenda.

The concept of green business is not new, but over the last decade has led to the emergence of the development of green practices to meet sustainability. These practices include different areas such as ecological, social and economic. There are several practices that can be followed in a green approach, for instance, 4R’s that focus on Reduction, Reuse, Recycle and Recovery; energy saving; green packing; eco-cleaning; eco-labelling; use of renewable resources are examples of green practices adopted by companies towards sustainability (Ahmad, 2016; Čekanavičius, Bazytė & Dičmonaitė, 2014; Ghisellini et al., 2016).

In spite of all these concerns, a key challenge related to sustainability in the industrial sector remains to the difficulty of applying this concept on their activities, and at the same time, demonstrate to managers its contribution for the company, and also for the environment and social aspects. Thorlakson et al. (2018) defend that despite companies have been seen as a source of environmental problems as a result of their production processes, the development of initiatives towards a green supply chain emerges as an alternative to build environmental-friendly practices in the context of the industrial sector.

Under such a background, this paper aims to investigate the level of environmental practices implemented by a set of Portuguese companies, which could contribute to understand the actual scenario of sustainable practices in these companies.

**Methodology**

In order to achieve the objective of this research several stages were considered. Figure 1 summarizes the main stages carried out in this research, namely (1) an analysis of the current literature on green and sustainable practices; (2) based on the literature review a questionnaire was designed to addressing issues related to sustainable practices; (3) a case study was chosen as strategy to assess a set of companies focusing on the 02 companies consulted through an online questionnaire (the sample was defined for convenience, due to time and budget constraints) (4); then a
statistical analysis was performed, and the main results draw, finally conclusions and directions for future works are presented (5).

**Figure 1**
Methodological approach

![Methodological approach diagram]

This research was inspired in a previous work developed by Jabbour et al., (2013), where the authors present a survey to assess the relationship between lean and green practices in the automobile industry. Here, this research focuses on the use of a quantitative method, firstly to assess environmental practices adopted by companies operating in the northern region of Portugal and secondly, to assess its level of implementation. Then, aiming to validate the questionnaire, a first attempt was made, and a pre-test with 10 companies was carried out. Then, an initial sample was defined by convenience and comprised by 700 companies. After screening the initial sample, an online questionnaire was sent to the 700 companies of our database, and 102 answered with the completely filling, it was taken as a final sample for this research, which means that the percentage rate is near of 15%.

**Table 1**
Practices of “Environmental Management” analyzed

<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>EM1</td>
<td>Clear environmental management policy</td>
</tr>
<tr>
<td>EM2</td>
<td>Environmental training for all employees</td>
</tr>
<tr>
<td>EM3</td>
<td>3Rs (Reduction, Reuse and Recycling applied in water, electricity and paper)</td>
</tr>
<tr>
<td>EM4</td>
<td>Development of products with lower environmental impacts</td>
</tr>
<tr>
<td>EM5</td>
<td>Development of productive process with lower environmental impacts</td>
</tr>
<tr>
<td>EM6</td>
<td>Selection of suppliers based on environmental criteria</td>
</tr>
<tr>
<td>EM7</td>
<td>Environmental management system (ISO 14001 or others)</td>
</tr>
<tr>
<td>EM8</td>
<td>Voluntary disclosure of environmental performance information</td>
</tr>
</tbody>
</table>

Source: Authors’ work

The questionnaire is divided into two parts: the first one related to the companies' characterization, with questions related to the dimension of the company, number of
employees; and the second one concerning to measurement of environmental practices as described in Table 1. For the second part, a five-point Likert scale was adopted as a tool to assess the company’s performance. The scale comprises five levels of agreement, ranging from (1) “Not implemented” to (5) “Completely implemented”. The main findings in this research are discussed in the next chapter. Statistical analysis has been conducted using IBM SPSS version 24.

Results and discussion

Preliminary analysis

The proposed questionnaire was developed through the Google Docs platform, in order to be available for the selected companies answer it. The sample (see Table 2) comprise 32.4% of micro-companies, 25.5% of small companies, 16.7% of medium size, and 25.5% of large companies. Regarding the number of works associated, the results showed that mostly of the consulted companies have more than three workers. The results also showed that a great number of companies had a turnover (by year), more than 5 million euros (36.3%).

Table 2
Technical record of participating companies

<table>
<thead>
<tr>
<th>Dimension on the company (number of employees)</th>
<th>%</th>
<th>Number of employees associated with logistics</th>
<th>%</th>
<th>Turnover (in euros)</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Micro (&lt; 10)</td>
<td>32.35</td>
<td>[0;3)</td>
<td>34.31</td>
<td>[0;100k)</td>
<td>13.7</td>
</tr>
<tr>
<td>Small (10-50)</td>
<td>25.49</td>
<td>[3;6)</td>
<td>20.59</td>
<td>[100k; 250k)</td>
<td>10.8</td>
</tr>
<tr>
<td>Medium (50-250)</td>
<td>16.67</td>
<td>[6;9)</td>
<td>5.88</td>
<td>[250k; 500k)</td>
<td>9.8</td>
</tr>
<tr>
<td>Large (&gt;250)</td>
<td>25.49</td>
<td>[9;12)</td>
<td>9.80</td>
<td>[500k; 1M)</td>
<td>10.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>[12;15)</td>
<td>1.96</td>
<td>[1M; 5M)</td>
<td>18.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>15 or more</td>
<td>27.45</td>
<td>5M or more</td>
<td>36.3</td>
</tr>
</tbody>
</table>

Source: Authors’ work

Regarding environmental impacts, it was one of the most important issues related to the production process in the industrial sector. In this direction, green practices are considered as key instruments to ensure the minimization of these impacts (Alves et al., 2019). The results presented in Table 3 summarizes the descriptive statistics associated with eight environmental practices proposed in this research. Results showed that all items were answered using the entire scale, meaning that the level of implementation of the environmental practices from the consulted companies are presented in different stages. These values are in line with the results obtained by Jabbour et. al (2013), where the measures less implemented are the last ones.

The results also showed that the lowest averages are related to environmental management system (EM7) and the selection of suppliers based on environmental criteria (EM6). These values can be explained by the fact that these measures imply more financial for business. The standard deviation does not present great discrepancies between items. Through the alpha analysis of Cronbach, it was obtain values greater than 0.7, which indicates a good internal reliability of the questionnaire.
### Table 3
Descriptive statistics and reliability for environment management practices

<table>
<thead>
<tr>
<th>Item</th>
<th>Min</th>
<th>Max</th>
<th>Mean</th>
<th>St. Dev.</th>
<th>Sk</th>
<th>Kurt</th>
<th>Cronbach’s alpha</th>
</tr>
</thead>
<tbody>
<tr>
<td>EM1</td>
<td>1</td>
<td>5</td>
<td>3.45</td>
<td>1.087</td>
<td>-0.698</td>
<td>0.031</td>
<td>0.895</td>
</tr>
<tr>
<td>EM2</td>
<td>1</td>
<td>5</td>
<td>3.28</td>
<td>1.146</td>
<td>-0.540</td>
<td>-0.393</td>
<td></td>
</tr>
<tr>
<td>EM3</td>
<td>1</td>
<td>5</td>
<td>3.40</td>
<td>1.017</td>
<td>-0.649</td>
<td>0.262</td>
<td></td>
</tr>
<tr>
<td>EM4</td>
<td>1</td>
<td>5</td>
<td>2.77</td>
<td>1.342</td>
<td>-0.154</td>
<td>-1.411</td>
<td></td>
</tr>
<tr>
<td>EM5</td>
<td>1</td>
<td>5</td>
<td>2.78</td>
<td>1.302</td>
<td>-0.193</td>
<td>-1.265</td>
<td></td>
</tr>
<tr>
<td>EM6</td>
<td>1</td>
<td>5</td>
<td>2.51</td>
<td>1.391</td>
<td>0.193</td>
<td>-1.416</td>
<td></td>
</tr>
<tr>
<td>EM7</td>
<td>1</td>
<td>5</td>
<td>2.45</td>
<td>1.558</td>
<td>0.455</td>
<td>-1.406</td>
<td></td>
</tr>
<tr>
<td>EM8</td>
<td>1</td>
<td>5</td>
<td>2.61</td>
<td>1.415</td>
<td>0.236</td>
<td>-1.330</td>
<td></td>
</tr>
</tbody>
</table>

Source: Authors’ work

Following this analysis, the results showed in Figure 2 present the intervals of 95% of confidence for the average answers of the companies. The circle refers to the mean value, and the interval represents 95% of the probability that the calculated interval from some future experiment encompasses the true value of the mean of the population. These results confirm the results from Table 3, showing that the first measures have a higher level of implementation, while the latter is still starting.

![Figure 2](image)

Source: Authors’ work

### Correlation and Principal Component Analysis
Table 4 shows the correlation between environmental practices. For the cases of EM4 and EM5, they achieved the highest correlation coefficient (0.816). These relationships are considered as important measures for companies, it because if the company take into account environmental concerns in the design of product/service, the production process could take into account green practices. For the case of EM1 and EM2, the results also show a high correlation (0.778). It can be justified due to the fact that these companies have a clear environmental policy in place, also because the employees are involved in the company’s policies. For the environmental practices,
the results showed that in order to develop strategic/finance policies, including green practices, it is considered as an important dimension to be addressed by companies.

Table 4
Matrix correlation between environment management practices

<table>
<thead>
<tr>
<th>Item</th>
<th>EM1</th>
<th>EM2</th>
<th>EM3</th>
<th>EM4</th>
<th>EM5</th>
<th>EM6</th>
<th>EM7</th>
<th>EM8</th>
</tr>
</thead>
<tbody>
<tr>
<td>EM1</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EM2</td>
<td>0.778</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EM3</td>
<td>0.578</td>
<td>0.674</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EM4</td>
<td>0.403</td>
<td>0.467</td>
<td>0.553</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EM5</td>
<td>0.468</td>
<td>0.565</td>
<td>0.619</td>
<td>0.816</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EM6</td>
<td>0.436</td>
<td>0.548</td>
<td>0.497</td>
<td>0.635</td>
<td>0.662</td>
<td>1.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EM7</td>
<td>0.621</td>
<td>0.570</td>
<td>0.390</td>
<td>0.385</td>
<td>0.380</td>
<td>0.372</td>
<td>1.000</td>
<td></td>
</tr>
<tr>
<td>EM8</td>
<td>0.425</td>
<td>0.478</td>
<td>0.558</td>
<td>0.511</td>
<td>0.620</td>
<td>0.615</td>
<td>0.350</td>
<td>1.000</td>
</tr>
</tbody>
</table>

Source: Authors’ work

In this section, a Principal Component Analysis was carried out (see Table 5).

Table 5
Principal Component Analysis

<table>
<thead>
<tr>
<th>Item</th>
<th>Communalities</th>
<th>Loadings (Varimax rotation)</th>
<th>KMO Measure</th>
<th>Bartlett’s test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Component 1</td>
<td>Component 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EM1</td>
<td>0.837</td>
<td>0.256</td>
<td>0.878</td>
<td></td>
</tr>
<tr>
<td>EM2</td>
<td>0.811</td>
<td>0.404</td>
<td>0.805</td>
<td></td>
</tr>
<tr>
<td>EM3</td>
<td>0.633</td>
<td>0.594</td>
<td>0.530</td>
<td></td>
</tr>
<tr>
<td>EM4</td>
<td>0.759</td>
<td>0.848</td>
<td>0.201</td>
<td></td>
</tr>
<tr>
<td>EM5</td>
<td>0.833</td>
<td>0.873</td>
<td>0.266</td>
<td></td>
</tr>
<tr>
<td>EM6</td>
<td>0.692</td>
<td>0.788</td>
<td>0.268</td>
<td></td>
</tr>
<tr>
<td>EM7</td>
<td>0.670</td>
<td>0.169</td>
<td>0.801</td>
<td></td>
</tr>
<tr>
<td>EM8</td>
<td>0.617</td>
<td>0.738</td>
<td>0.269</td>
<td></td>
</tr>
</tbody>
</table>

Source: Authors’ work

The Kaiser-Meyer-Olkin (KMO) and the Bartlett sphericity test indicated that the adequacy of the data for the accomplishment of the factorial analysis (Kline, 2011), since the first result is close to 1, and the Bartlett test lead to the significance level lower than 0.05. Regarding the communalities (after extraction), the analysis showed all variables have values greater than 0.5, which is recommended by Field (2005). Only the first two components have eigenvalues over 1.00, explaining over 70% of the total variability in the data. The factor loadings were greater than 0.5 for all items, suggesting a good representation of their attributes.

Analysing the loadings of each component, it is possible to confirm that items EM4, EM5, EM6 and EM8 are best represented by component 1, that can call by product and process issues. The items EM1, EM2 and EM4, related to training of the employees. The item EM3 is equal represented in both components; this could be explained by the fact that the 3Rs policy can be considered as part of the environment management system already settled, meaning that they have the system but could not be certificated by the standard ISO 14001.
**Dimension’s analysis by company**

To understand the level of implementation of green measures, it should be more scrutinized if we take the dimension of the company as a factor of analysis. Figure 3 presents the level of environmental management practices of the consulted companies, by the dimension. The results showed that the large ones are at the forefront regarding the implementation of environmental practices.

*Figure 3*
Average level of environment management practices, by companies’ dimension

To ensure the impact of these measures, a Kruskal Wallis test was also conducted to examine the differences in practices according to the types of companies inquired (Table 6). At the same time, it was possible to observe that for all companies, the last three environmental practices present the lowest scores; this could be interpreted by the lack of consciousness about the benefits of implementing these practices, and also the scarcity of financial support forwarded to green procedures.

Statistically significant difference exists in almost all the measures, except in EM3 and EM5 (with p<0.05); this means that there are significant differences in the stages of companies related to green issues, taking into account the dimension of them (Table 6). This can be explained by the fact that the 3Rs policy (EM3) is already a measure very common and the development of the production process with lower environmental impacts (EM5) is also a great concern related to the reduction of waste. For the items, the hypothesis H0 was rejected in the Kruskall Wallis test, a Dunn-Bonferroni test was performed (see Table 6). This post hoc test reports the results among multiple pairwise comparisons. As expected, the major differences between companies arise in the pairs micro-large and small-large companies.
Table 6 – Kruskal Wallis Test and Post hoc Dunn-Bonferroni test for green measures (group variable: dimension of the company)

<table>
<thead>
<tr>
<th>Item</th>
<th>EM1</th>
<th>EM2</th>
<th>EM3</th>
<th>EM4</th>
<th>EM5</th>
<th>EM6</th>
<th>EM7</th>
<th>EM8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kruskal-Wallis test (sig.)</td>
<td>0.000</td>
<td>0.000</td>
<td>0.089</td>
<td>0.027</td>
<td>0.082</td>
<td>0.032</td>
<td>0.000</td>
<td>0.004</td>
</tr>
<tr>
<td>Dunn-Bonferroni test (sig.)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Micro-Small</td>
<td>0.308</td>
<td>0.481</td>
<td>---</td>
<td>0.496</td>
<td>---</td>
<td>0.678</td>
<td>0.329</td>
<td>0.166</td>
</tr>
<tr>
<td>Micro-Medium</td>
<td>0.135</td>
<td>0.211</td>
<td>---</td>
<td>0.532</td>
<td>---</td>
<td>0.494</td>
<td>0.196</td>
<td>0.031</td>
</tr>
<tr>
<td>Micro-Large</td>
<td>0.000</td>
<td>0.000</td>
<td>---</td>
<td>0.032</td>
<td>---</td>
<td>0.005</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>Small-Medium</td>
<td>0.566</td>
<td>0.707</td>
<td>---</td>
<td>0.980</td>
<td>---</td>
<td>0.759</td>
<td>0.676</td>
<td>0.368</td>
</tr>
<tr>
<td>Small-Large</td>
<td>0.000</td>
<td>0.001</td>
<td>---</td>
<td>0.008</td>
<td>---</td>
<td>0.023</td>
<td>0.000</td>
<td>0.042</td>
</tr>
<tr>
<td>Medium-Large</td>
<td>0.002</td>
<td>0.001</td>
<td>---</td>
<td>0.017</td>
<td>---</td>
<td>0.087</td>
<td>0.002</td>
<td>0.364</td>
</tr>
</tbody>
</table>

Source: Authors’ work

Finally, for each company, the level of implementation of environmental measures was averaged. Figure 4 shows a summary of the answers: each ball represent the average level of each company in terms of environmental issues. From the results presented, it is possible to observe that most of the large companies are located in the upper right corner, while the micro and small companies have the lowest levels, showing that there is huge progress to be done.

Figure 4
Average level of environment management practices

Source: Authors’ work

Conclusions
Sustainable practices have become a trend issue to describe activities connected to environmental and sustainable awareness. Such initiatives intend to support companies on reducing their environmental impact. For companies, it can be seen as benefits such as increase profitability, resilience and positive social and environment impacts when addressing green thinking strategies.
This research contributes then with insights to the current literature on sustainability and green practices within the industrial sector. Also, the analysis of a set of companies consulted, contributes to understand which green practices have been adopted by companies operating in the north of Portugal.

Recognizing the importance of these initiatives we proposed an analysis of the implementation of these practices taking a set of companies as a sample. Results from the literature confirmed that sustainable practices have led companies to develop environmental strategies, such as green initiatives which have been contributing to companies save costs, meet compliance requirements, and also to create a sustainable network among customers.

Regardless of the green practices adopted by the consulted companies, the results showed that there are mostly related to the implementation of 3Rs initiatives (EM3). Meaning that the use of strategies focusing on reuse, reduction and recycling applied in areas such as water and electricity consumption, were the main focus of companies when developing green practices. Also, practices related to the development of productive processes considering low environmental impacts (EM5) were highlighted in the results. Surprisingly, the results also showed that part of the consulted companies have setted a clear environmental management policy (EM1).

In summary, from the companies’ consulted, the research showed that they have a long path to go toward the implementation of sustainable practices, with few exceptions for large companies that have well-defined policies on sustainability field as economic resources to implement it.

Despite being an initial analysis, the results showed that for the consulted companies, the environmental questions are still on a development process. Particularly, small companies face several barriers to implement green operations, especially the ones related to ones that are necessary to obtain certification. To face these barriers, there a positive indication that the Sustainable Development Goals have been supporting companies to developed strategies focusing on economic, environmental and social issues. The strength of green practices could also support the industrial sector on enhancing the SDGs.

The study allowed suggesting some implications regarding the use of green practices in Portuguese’ companies. However, the research is not free from limitation. First, the data collection is limited to a region in Portugal. The approach that we present here should be replicated in other regions in the country, to check the green practices and claims news results. Also, the need for a better understanding about causality between green practices and the economic performance of the consulted companies could be addressed as a perspective, both are potential future directions for future developments to be taken in this field.

Acknowledgement
This research was supported by CAPES and Science Without Borders scholarship, BEX Process 10.190-13-9 (Alves); the FCT – Fundação para a Ciência e Tecnologia, through Project UID/EMS/04005/2019 (Silva); and UIDB/04106/2020 and UIDP/04106/2020 (Rodrigues).

References


21. PORDATA. (2020), “Pequenas e médias empresas em % do total de empresas: total e por dimensõo” (Small and medium-sized enterprises as a% of total enterprises: total and by size), available at:


About the authors

Wellington Alves is a Scientific Researcher at the Algoritmi Research Centre (SINOVPROC Project) from University of Minho. He is also Assistant Professor at Business School of the Polytechnic Institute of Viana do Castelo. Received his Ph.D. degree in Industrial and Systems Engineering from University of Minho, in 2018, with work in Evaluation of Sustainability in the Mining Sector. Participated in several international conferences, under a Science Without Boarders Grant. He is author of several publications, in international conferences and in scientific journals. Currently he performs scientific research in the areas of sustainability, social innovation, circular economy and green Logistics. The author can be contacted at wellingtonalves@esce.ipvc.pt

Ângela Silva, PhD, is Adjunct Professor at the Business School at Instituto Politécnico de Viana do Castelo, Portugal. She holds a Ph.D. in Engineering of Production and Systems from School of Engineering, University of Minho. She develops her research work in the COMEGI Research Center, in Operations Management and Logistics and also Modelling and Optimization of Energy Systems. At the University of Minho she is a researcher at the ALGORITMI Research Center in the “Industrial Engineering and Management (IEM)’’ research line, group of “Ergonomics and Human Factors (EHF)”. Currently, she supervises Ph.D. and MSc projects in these areas, being a co-author of several scientific papers published in International Journals and Conferences. The author can be contacted at angela.a@esce.ipvc.pt

Helena Sofia Rodrigues, Ph.D. is an Adjunct Professor at the Business School at Instituto Politécnico de Viana do Castelo, Portugal. She received PhD in Applied Mathematics at University of Aveiro with the dissertation thesis “Optimal Control and Numerical Optimization Applied to Epidemiological Models”. Her main research interests are optimal control, epidemiological models, numerical optimization and modelling. She is actively engaged in science projects (European COST ACTION 16227, Portuguese FCT - Fundação para a Ciência e Tecnologia through UIDB/04106/2020 and UIDP/04106/2020 and FONDOCYT - National Research, Science and Technology Fund of Dominican Republic). The author can be contacted at sofiarodrigues@esce.ipvc.pt
Comparison of Two Network-Theory-Based Methods for detecting Functional Regions

Samo Drobne
Faculty of Civil and Geodetic Engineering, University of Ljubljana, Ljubljana, Slovenia
Alberto Garre
Laboratory of Food Microbiology, Wageningen University & Research, Wageningen, the Netherlands
Eloy Hontoria
Technical University of Cartagena / Business Management, Cartagena, Spain
Miha Konjar
Locus d.o.o., Solkan, Slovenia

Abstract

Background: Functional regions are abstract, uniformly defined territorial units that form an important basis for many development strategies of a country or a region. Objectives: This study analyses the application of network theory to the detection of such regions. Methods/Approach: Functional regions are analysed using two methods based on the graph theory: the Walktrap algorithm and the chain approach. The quality of the two regionalization methods is analysed using the fuzzy set theory with the revised method. Slovenia was used as a case study. Results: The Walktrap algorithm generated eight functional regions; seven of them corresponded to those identified in previous studies. The only difference occurred in the northwestern mountainous part of Slovenia. The chain approach led to similar results, although it resulted in a huge functional urban region of the capital Ljubljana. Conclusions: The results show that the Walktrap algorithm calculates regions that are more closed, where more workers find work in the home region, than the chain approach.

Keywords: functional regionalisation, graphs, Walktrap algorithm, chain method, fuzzy sets, Slovenia

JEL classification: C02, J61, C44, R23

Paper type: Research article

Received: 28 Jan, 2020
Accepted: 19 Apr, 2020


DOI: 10.2478/bsrj-2020-0013
Introduction
Spatial organisation is a crucial factor in understanding and explaining various socio-economic phenomena. This knowledge is necessary for sustainable spatial development, spatial planning and the implementation of various spatial policies aimed at a more efficient organisation (Coombes et al., 2012; Erlebach et al., 2016; Halás et al., 2018). However, there are still administrative regions used by many governments for policymaking, resource allocation and research that are delimited for historical reasons (Ball, 1980; Casado-Díaz, 2000; Cörvers et al., 2009. Such regions, in many cases, do not reflect the actual conditions of that particular place. Consequently, in recent years efforts have been directed towards identifying and delimiting functional regions that are more meaningful than the regions currently in use.

Ullman (1980), Karlsson & Olsson (2006) and many other researchers defined a functional region (FR) as a territorial area with a high frequency of intraregional interactions. In this context, interactions may relate, for example, to trade exchanges, financial and information flows or the movement of people. A FR is therefore a group of basic spatial units (BSUs) grouped based on spatial flows or interactions between them. A process of grouping basic spatial units into functional regions with the aim of generalising the functional flows in the addressed area is called functional regionalization. Drobne (2016: 13) describe FR as “an area with generalised patterns of flows and interactions in space”.

A functional region is an abstract spatial concept (Pálóczi et al., 2016). Therefore, there is no single method for delimiting them and it is not straightforward interpreting the fact that the application of different methods, although using the same data, can lead to significantly different results (Laan & Schalke, 2001). In the literature, there are three general approaches to FR taxonomy (Halás et al., 2018): graph-theoretical methods (e.g. Benassi et al., 2015; Drobne et al., 2010; Holmes & Haggett, 1977; Karlsson & Olsson, 2006; Konjar et al., 2010; Nystuen & Dacey, 1961), methods of numerical taxonomy (e.g. Masser & Brown, 1975; Masser & Scheurwater, 1978, 1980) and rule-based methods (e.g. Coombes et al., 1986; Coombes & Bond, 2008; Halás et al., 2015). When FRs are modelled, they can be valued using the fuzzy set theory approach. Feng (2009) and Watts (2009, 2013) show how we can quantify the degree of uncertainty in individual BSUs. The same methodology can be applied to the FRs.

Network theory provides a suitable framework for the analysis of interactions in complex systems, which can be applied for the recognition of FRs. A network can be defined as a mathematical object consisting of vertices and edges (Newman, 2010). The vertices represent the analysed units, while the edges describe the relationships between them. Thanks to this general definition, a number of problems have been solved with network theory models, from the structure of the World Wide Web (Faloutsos et al., 1999) to food distribution systems (Garre et al., 2019).

One of the reasons for the widespread use of networks is also that the analysis of their topology can provide meaningful information about the modelled system (Newman, 2010). A wide range of indices has been defined, which describe different topological properties of the network and thus of the modelled system. Boss et al. (2004), for example, analysed the degree of distribution and clustering of a network describing the relationships between banks in Austria in order to assess the robustness of the system. However, the amount of information that can be obtained using these indices alone is limited. One of the network attributes that is difficult to understand with simple indexes is the existence of clusters. In this context, clusters are defined as a group of vertices that are highly interconnected. The identification of the clusters is very complex and (although many algorithms are available) not yet satisfactorily
solved (Fortunato, 2010). Nevertheless, there are several numerical algorithms that can estimate cluster distribution that have been used in a variety of situations (e.g. Clauset et al., 2008; Lehmann et al. 2008; Ronhovde & Nussinov, 2009), including some case studies that relate to the spatial organisation of different areas (Ke et al., 2017; Khatoon & Banu, 2019).

In our study, we calculate functional regions for Slovenia using two methods based on graph theory: Walktrap algorithm (Pons & Latapy, 2006) and chain method (Drobne et al., 2010; Karlsson & Olsson, 2006; Konjar et al., 2010). The quality of both regionalization methods is analysed using fuzzy set theory (Feng, 2009; Watts, 2009, 2013) with the revised approach. The results for Slovenia show that the Walktrap algorithm calculates more self-contained regions, i.e. regions with a higher relative frequency of intraregional flows, than the chain approach. This is the first time that the Walktrap algorithm has been used to analyse functional regions by commuting data on the macro spatial level; and it is the first time that the functional region analysis algorithm has been used for Slovenia. A short report on the study was published in (Drobne et al., 2019).

**Methodology**

In a case study we used a data for Slovenia for the year 2017. The geodata for the 212 municipalities were taken from the “Free Access Database” from the Surveying and Mapping Authority of the Republic of Slovenia (GURS, 2018) and statistical data on inter- and intra-municipal labour commuting flows were obtained from the “SI - Stat Data Portal” of the Statistical Office of the Republic of Slovenia (SURS, 2018).

Gabrovec and Bole (2009) pointed out some methodological problems that may arise from the use of commuter statistics. Two potential problems are worth mentioning here: (a) the first is the incorrect registration of the place of residence or work and (b) the second is the supposed registration of commuting. Ad (a) When modelling FRs at the macro level, we consider in particular the largest relative interactions between the residential community and the working community. Due to the relativisation of the absolute flows of more than 400,000 commuters between Slovenian municipalities, this problem does not have a significant impact on the allocation of the municipality to a particular FR. Ad (b) The nature of work has changed considerably in recent decades. There are more and more professions in which workers can work at home, so that they only go to work a few times a week as needed. The problem mentioned does not concern the formation of FRs, since they are actually defined by the functional connections of the territory - which is particularly exposed in the case of telework.

With data on the commuter statistics, we created an interaction matrix of a total of 44,944 (212x212) cells. The matrix consisted of 31,060 (69.1%) empty cells, 4764 (10.6%) cells that noted only 1 commuter, and only 283 (0.6%) cells that recorded 500 commuters or more. The interaction matrix recorded a total of 830,564 registered commuters (working population), but only 432,108 (52.2%) of them commuted between municipalities. The rest, i.e. 398,456 (47.8%) of the working population, thus lived and worked in the same municipality. The eleven largest inflows of 124,227 (28.7%) commuters ended in Slovenia’s largest employment centre, i.e. the capital Ljubljana, while outflows from Ljubljana amounted to 20,402 (4.7%) commuters. Figure 1 shows the inter-municipal commuter flows for Slovenia in 2017; note that only flows with 50 and more commuters are shown on the map.

Regional centres in the Figure 1 were stated in (SPRS, 2004).

According to the Spatial Development Strategy of Slovenia (SPRS, 2004), there are fifteen urban centres of national significance in Slovenia: Ljubljana, Maribor, conurbation Koper–Izola–Piran, Celje, Kranj, Novo mesto, Nova Gorica, Murska
Sobota, Velenje, Postojna, Ptuj, and conurbations Slovenj Gradec–Ravne na Koroškem–Dravograd, Jesenice–Radovljica, Zagorje ob Savi–Trbovlje–Hrastnik, and Krško–Brežice–Sevnica. These centres are also known as regional centres of Slovenia. Despite the large number of regional centers in a relatively small country, most jobs and economic activities are concentrated in the functional urban areas of Ljubljana, Maribor, Celje, Koper - Izola - Piran, Kranj, Novo mesto, Velenje and Nova Gorica (Drobne & Bogataj, 2014).

Figure 1
Inter-municipal labour commuting flows in Slovenia in 2017

We analysed the FRs in Slovenia using two methods based on network theory. For this purpose, the complex system of labour commuting between Slovenian municipalities in 2017 was described as a network. In our study, the municipal centroids are the vertexes of the network, which are connected by an edge if the inter-municipal commuter flows were recorded in the analysed period. Weights \(w_{ij}\) were assigned to each edge according to the number of commuters registered between the two municipalities. Therefore, \(w_{ij}\) represents the number of commuters from municipality \(i\) to \(j\). Using the Walktrap algorithm (Pons & Latapy, 2006) and the chain approach (Drobne et al., 2010; Karlsson & Olsson, 2006; Konjar et al., 2010) we identified communities in the network - i.e. functional regions of the inter-municipal labour commuting flows.

The Walktrap algorithm is a heuristic algorithm that groups the vertices of the network on the basis of a distance, \(r\), which measures the connectivity of two nodes, i.e. municipal centroids. The distance \(r_{ij}\) between the nodes \(i\) and \(j\) is as defined in Equation 1, where \(P^t_{ik}\) is the transition probability from node \(i\) to \(k\) in \(t\) steps, \(d(k)\) is the degree of node \(k\) and \(n\) is the number of nodes in the network.
In the Walktrap algorithm, the transition probabilities are estimated using random walk. In short, \( Q \) random walks of length \( t \) are taken from randomly selected nodes. At each transition, the walker travels from node \( i \) to node \( j \) with the probability \( \frac{w_{ij}}{\sum_k w_{ik}} \). Then the transition probabilities \( P^t_{ik} \) are calculated as the fraction of walkers that ended in node \( k \) after \( t \) steps. Once the distance matrix \( r_{ij} \) has been calculated, the vertices are aggregated using a hierarchical clustering algorithm. The Walktrap algorithm was applied using the implementation contained in the \textit{igraph} R package (Csardi & Nepusz, 2006), with R version 3.4.3 (R Core Team, 2016). The parameter \( t \) was set to four, while \( Q \) was increased until the results converged (i.e. no variation of the functional regions for independent runs). When applied to the inter-municipal labour commuting data, we also tested \( t = 2, 3, 5, 6 \), but only \( t = 4 \) generated realistic and compact FRs. To the authors’ knowledge, this is the first time that Walktrap algorithm was used to analyse functional regions by commuting data at the macro spatial level.

The second method used to calculate FRs was the chain approach, which was introduced and applied by Karlsson and Olsson (2006) and later improved by Drobne et al. (2010) and Konjar et al. (2010). The first step in this approach is to identify the centres of the FRs. They are defined as the most important employment centres in the area studied, which are highly self-sufficient. Therefore, the centres can be defined nominally or calculated as the most self-sufficient centres. A municipality is highly self-sufficient if the majority of the active population works in the home municipality; this percentage is usually set at 66.67% or more (Drobne et al., 2010; Karlsson & Olsson, 2006; Konjar et al., 2010). Although methods for this step are described in the literature (Drobne et al., 2010; Konjar et al., 2010), in order to facilitate comparison with the Walktrap algorithm, the centres of the FRs calculated by the Walktrap algorithm were also used for the chain approach. In a second step, chains of nodes are formed by adding municipalities to self-sufficient municipalities, i.e. predefined centres of FRs, until the condition defined in Equation (2) is satisfied. This condition defines the boundary of \( FR_i \), which is the break line, where the attraction theoretically corresponds to the two nearest self-sufficient municipalities:

\[
FR_i = \{ x : w_i(x) \geq w_j(x) \} \tag{2}
\]

In (2), \( i \) and \( j \) denote two FR's centres connected by a line, where intermediate point between the end points \( i \) and \( j \) is denoted with \( x \). At a location \( x \), the commuting frequency to the centre \( i \) is \( w_i(x) \). The chains were calculated in three different ways defined by three types of municipalities (nodes): (a) the chains of the municipalities that were directly connected to the centre by their maximum outflow; (b) the chains of municipalities that were indirectly connected with their maximum outflow to the centre via a non-self-sufficient municipality (such chains are determined iteratively); and (c) the chains of the pairs of municipalities, which presented to each other the destination of their maximum outflow, were connected to the functional region according to the second maximum flow. As proposed by Karlsson and Olsson (2006), the chain was allowed to have three links in our application for Slovenia. If more links existed, the link was broken at the weakest point. Moreover, we tested the approach by allowing three and four links, without any impact on the results. The chains were
automatically calculated in our own program (Konjar et al., 2010) based on the Java platform.

After identifying the FRs with both algorithms, we compared the quality of both regionalization methods using Fuzzy Set Theory (FST), as proposed by Feng (2009) and Watts (2009, 2013). The FST extends Crisp Set Theory, by allowing one element (in this study BSU) to partially belong to a group (in this study to FR). Consequently, elements can belong to several groups at the same time. By using the FST approach, where each BSU can be partially allocated to a number of fuzzy FRs, we can identify potential misallocations of BSUs in the FRs by measuring a membership function. A membership function for BSU \( i \) in relation to fuzzy residential FR \( m \) is defined as

\[
M'_{im} = \sum_{j \in (g)_m} \frac{w_{ji}}{w_i},
\]

where BSU \( i \) belongs to FR \( m \) on the basis of a regionalisation method. And, the membership function with respect to fuzzy local employment FR \( m \) is defined as

\[
M''_{im} = \sum_{j \in (g)_m} \frac{w_{ij}}{w_i}.
\]

Feng (2009) suggested to calculate the common membership function values with respect to a fuzzy FR, \( m \), \( M_{im} \), as an arithmetic mean of \( M'_{im} \) and \( M''_{im} \). But \( M'_{im} \) and \( M''_{im} \) are relative values. For this reason, we suggest calculating the common membership function values as a geometric mean of the corresponding function values:

\[
M_{im} = \sqrt[2]{M'_{im} \cdot M''_{im}}.
\]

To analyse the values of the membership function of each municipality, we mapped these values into the FRs, as proposed by Feng (2009). We also calculated the geometric mean membership values for each FR individual and for the whole system of FRs in Slovenia. This enabled us to compare the quality of the individual regionalisation.

In this study, we extended the classical approach of modelling and analysing FRs with manual reshaping of FRs. In the last step, we moved the municipalities with very low membership values to the neighbouring FRs when new membership values were higher.

The quality of functional regionalization - i.e. the calculation and modelling of functional regions and the analysis of the quality of functional regions - was performed in Mathematica 11.3 by using our programme code (Drobne, 2016; Drobne & Lakner, 2016).

**Results**

The results of the two applied regionalization methods, both based on network theory methods, are shown in Figure 2. The Walktrap algorithm (Figure 2a) generated eight FRs of Slovenia. Seven of them were expected and are consistent with previous research (see e.g. Drobne et al., 2010; Drobne, 2016; Konjar et al., 2010), these FRs are FR Murska Sobota, FR Maribor, FR Celje, FR Slovenj Gradec, FR Ljubljana, FR Novo mesto, and FR Nova Gorica. However, FR Tolmin, which consists of only three relatively large municipalities surrounded by high mountains, has never been modelled at the macro level of Slovenia – compare this result also with fifteen regional centres of national importance in Figure 1. Instead of FR Tolmin, previous studies in the scientific
literature (Drobne, 2016; Drobne et al., 2010; Konjar et al., 2010) usually report FR Koper on the southwestern coastal region of Slovenia, while Koper is also one of the most important employment centres in Slovenia. Further analysis also revealed that the relationship of FR Tolmin to other FRs is much weaker than the relationships between FR with a more central location in Slovenia.

The result of the chain method (Figure 2b) is very similar to those of the Walktrap method. This is (partly) understandable since we used the same regional centres. The method estimates eight FRs, but there are differences between the sizes of the FRs calculated with each method. FR Ljubljana is much larger in the chain method, mostly at the expense of the FRs Celje and Novo mesto, which are consequently smaller than those calculated with the Walktrap algorithm. The influence of FR Ljubljana is even unexpected along the narrow strips of municipalities to the east. The remaining FRs are (almost) identical for both algorithms.

The quality analysis of the regionalisation procedures, i.e., the comparative analysis of the general membership values of FRs calculated with the FST approach, shows that the Walktrap algorithm generates FRs Ljubljana, Novo mesto, Celje and Murska Sobota with higher average membership values than the chain approach (see Figures 3a and 3b and Table 1). Furthermore, the mean membership values of almost all FRs generated by the Walktrap algorithm are higher or equal to the mean membership values of the FRs calculated by the chain method, the only exception being FR Slovenj Gradec.

In general, the municipalities with the highest membership values are in the centres of the FRs, while the municipalities with the lowest membership values are on the periphery of FRs. As far as FRs calculated according to the chain method are concerned, most of the municipalities with (very) low membership values are on the borderline between FRs. In most cases, these municipalities are also those that are assigned to a different FR by the Walktrap algorithm (i.e., in the border areas between the FRs Ljubljana, Celje and Novo mesto). Therefore, the chain algorithm may incorrectly assign some of these municipalities. On the other hand, in the FRs calculated by the Walktrap algorithm there are also some municipalities with low membership values. These municipalities are located on the border between the FRs Ljubljana and Novo mesto and Ljubljana and Nova Gorica and in the FR Slovenj Gradec, which is the only one with a lower average membership value compared to both FRs’ systems. These results, together with the higher mean membership values of the Walktrap algorithm, indicate that the Walktrap algorithm provides a better classification for the case under investigation.
Figure 2
Eight functional regions in Slovenia in 2017 defined with the inter-municipal labour commuting flows and generated by the Walktrap algorithm (Figure 2a) and chain method (Figure 2b).

Source: Authors’ work.
Note: Basic spatial unit (BSU) is municipality.
Figure 3
Membership values of Slovenian municipalities in the functional region to which they were located by using Walktrap algorithm (Figure 3b) and chain method (Figure 3b)

Figure 3a

Figure 3b

Source: Authors’ work.
Note: Basic spatial unit (BSU) is municipality.
In the last step of our research, we analysed whether reshipment of FRs can improve the quality of regionalization results. For this reason, in our study we had used $M < 0.6$ to move the municipalities on the border of the functional region with a very low value of membership function to the neighbour FR. Such cases were only included in the system of FRs calculated using the chain method, where we moved four municipalities along the border lines between FR Ljubljana, Celje and Novo mesto, as shown in Figure 4. The relocation of these four municipalities - namely Kozje (51), Dobrna (155), Vransko (189) and Mokronog - Trebelno (199) - to the neighbouring FR increased the membership values for both: for individual municipalities and for the FR system as a whole. The results of the improvement in the quality of regionalisation for the whole system are shown in Table 2, while the improvement in membership values for individual municipalities is as follows: Kozje (51) from 0.482 to 0.782, Dobrna (155) from 0.546 to 0.689, Vransko (189) from 0.534 to 0.716 and Mokronog - Trebelno (199) from 0.530 to 0.779. We can conclude, that all individual results have improved significantly.

**Table 1**
Mean membership values of the functional regionalization

<table>
<thead>
<tr>
<th>Functional Region / Slovenia</th>
<th>Mean membership value</th>
<th>Walktrap algorithm</th>
<th>chain method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slovenia</td>
<td>0.891</td>
<td>0.866</td>
<td></td>
</tr>
<tr>
<td>Murska Sobota</td>
<td>0.865</td>
<td>0.795</td>
<td></td>
</tr>
<tr>
<td>Maribor</td>
<td>0.884</td>
<td>0.880</td>
<td></td>
</tr>
<tr>
<td>Celje</td>
<td>0.854</td>
<td>0.782</td>
<td></td>
</tr>
<tr>
<td>Slovenj Gradec</td>
<td>0.836</td>
<td>0.849</td>
<td></td>
</tr>
<tr>
<td>Ljubljana</td>
<td>0.954</td>
<td>0.912</td>
<td></td>
</tr>
<tr>
<td>Novo mesto</td>
<td>0.849</td>
<td>0.794</td>
<td></td>
</tr>
<tr>
<td>Tolmin</td>
<td>0.839</td>
<td>0.839</td>
<td></td>
</tr>
<tr>
<td>Nova Gorica</td>
<td>0.860</td>
<td>0.860</td>
<td></td>
</tr>
</tbody>
</table>

Source: Authors’ work.

**Table 2**
Mean membership values of the corrected functional regionalisation with the chain method

<table>
<thead>
<tr>
<th>Functional region / Slovenia</th>
<th>Moved municipalities</th>
<th>Mean membership value after reshaping FRs</th>
<th>average</th>
<th>improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slovenia</td>
<td>4</td>
<td>0.874</td>
<td>+0.008</td>
<td></td>
</tr>
<tr>
<td>Murska Sobota</td>
<td></td>
<td>0.795</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Maribor</td>
<td></td>
<td>0.880</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Celje</td>
<td>+3</td>
<td>0.793</td>
<td>+0.011</td>
<td></td>
</tr>
<tr>
<td>Slovenj Gradec</td>
<td></td>
<td>0.849</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Ljubljana</td>
<td>-2 And +1</td>
<td>0.922</td>
<td>+0.010</td>
<td></td>
</tr>
<tr>
<td>Novo mesto</td>
<td>-2</td>
<td>0.842</td>
<td>+0.048</td>
<td></td>
</tr>
<tr>
<td>Tolmin</td>
<td></td>
<td>0.839</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Nova Gorica</td>
<td></td>
<td>0.860</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

Source: Authors’ work.
Discussion and conclusions

Several aspects of governance, such as spatial development or territorial planning, require an understanding of the organisation of space in order to be effective. Therefore, identifying functional regions can be (in)valuable for governments and other authorities. In the paper, we analysed FRs using the Walktrap algorithm and the chain approach. The results of the two methods based on graph theory were compared and analysed in detail using fuzzy sets with the improved approach. In the case studied (inter-municipal commuter flows for Slovenia for the year 2017), the Walktrap algorithm identifies more meaningful FRs than the chain approach: the Walktrap algorithm calculates FRs with a lower level of potentially misallocated BSUs.

It should be stressed that FRs are abstract concepts, whose exact definition may vary from application to application. Therefore, FRs that may be valid for one application may not be suitable for the analysis of other case studies. In this sense, fuzzy set theory offers a more flexible framework than traditional set theory and allows the definition of partial membership relationships. In the case study analysed in this study, this refers to the uncertainty that a particular municipality belongs to a FR. In this study, we have applied this result to compare the FRs identified with the Walktrap algorithm and the chain method, concluding that the FRs identified with the Walktrap algorithm are more self-contained. However, the application of fuzzy set theory in this context is not limited to the comparison of regionalization methods. For example, it could be used to define different scenarios varying the position of the municipalities with the highest uncertainty. However, these applications are not the subject of this article and remain for future work. In this study, we have showed only a principle on how the reallocation of a single BSU at the border between FRs with a very low
membership value could improve the results not only for this single unit, but also for the whole FRs' system.

In addition, network theory provides a good framework for the analysis of complex systems such as those analysed here. Although this study was limited to the identification of FRs based on community detection algorithms, a deeper analysis of network attributes could provide a meaningful insight into the structure of the system. For example, the topology of the commuter network in Slovenia could be compared with that of other countries to identify regions with a similar production system.

As a direction for future work, the algorithms analysed here could be compared with other graph-based methods of FRs identification (e.g. Benassi et al., 2015) as well as with other methods - e.g. with the most popular rule-based regionalisation method, i.e. CURDS's method (Coombes & Bond, 2008). Furthermore, network theory could be applied to analyse in detail the structure of functional regions at different spatial levels (micro, mezzo and macro). Furthermore, the results of the approach used in this study to assess functional regionalization should be compared with other approaches to quality assessment of functional regions, as recently proposed by Halás et al. (2019).

Acknowledgments: The authors acknowledge the financial support from the Slovenian Research Agency (research core funding P2-0406 Earth observation and geoinformatics and research projects J6-9396 Development of Social Infrastructure and Services for Community Based Long-Term Care and J5-1784 Creating Social Value with Age-Friendly Housing Stock Management in Lifetime Neighbourhoods), the Ministry of Economy and Competitiveness (MINECO) of the Spanish Government and European Regional Development Fund (project AGL2013-48993-C2-1-R) and to Ministry of Science, Innovation and Universities (MICINN, Project RTI2018-099139-B-C21), and FEDER. Alberto Garre was supported by a postdoctoral grant from the Fundación Seneca (20900/PD/18).

References
About the authors

Samo Drobne is an Assistant Professor and a vice-dean for educational affairs at the Faculty of Civil and Geodetic Engineering, University of Ljubljana (Slovenia). He teaches courses on statistics, geographical information systems (GIS) and spatial analyses in GIS. His main research fields include regional development and planning, spatial interaction models, functional regions, commuting, migration, spatial analysis in GIS, operational research in spatial systems. Currently, he is a member of the narrow working group for concepts and legislative bases for establishing provinces in Slovenia where he helps with the concepts of functional regions as bases for provinces. He is actively involved in several international and national research projects. The author can be contacted at samo.drobne@fgg.uni-lj.si

Alberto Garre is a postdoctoral researcher in Wageningen University & Research (The Netherlands). His main research field deals with the development of mathematical models and statistical analysis in the context of food science. This includes, for instance, kinetic models for shelf-life estimation or microbial risk assessment. The author can be contacted at alberto.garreperez@wur.nl

Eloy Hontoria is an Associate Professor and a vice-dean of Business Relations at the Technical School of Telecommunication Engineering, Technical University of Cartagena (Spain). He has a vast experience in logistics at the private sector and has extensive collaborations with industry. His research deals with applications of Operation Research to real Operation Management problems. The author can be contacted at eloy.hontoria@upct.es

Miha Konjar is currently working as an associate expert in a company Locus d.o.o. specialized in spatial information solutions. His research areas include regional development and planning, spatial analysis in GIS, detection and delineation of functional regions and land use research. Recently he finished his PhD on the topic of spatial and land use development. His work now is mainly focused on defining a set of indicators for the developing monitoring system for spatial development in Slovenia. The author can be contacted at miha.konjar@locus.si
Deep Learning Predictive Models for Terminal Call Rate Prediction during the Warranty Period

Aljaž Ferencek
Faculty of Organizational Sciences, University of Maribor, Slovenia

Davorin Kofjač
Faculty of Organizational Sciences, University of Maribor, Slovenia

Andrej Škraba
Faculty of Organizational Sciences, University of Maribor, Slovenia

Blaz Sašek
Faculty of Organizational Sciences, University of Maribor, Slovenia

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

Abstract

Background: This paper addresses the problem of products’ terminal call rate (TCR) prediction during the warranty period. TCR refers to the information on the amount of funds to be reserved for product repairs during the warranty period. So far, various methods have been used to address this problem, from discrete event simulation and time series, to machine learning predictive models. Objectives: In this paper, we address the above named problem by applying deep learning models to predict terminal call rate. Methods/Approach: We have developed a series of deep learning models on a data set obtained from a manufacturer of home appliances, and we have analysed their quality and performance. Results: Results showed that a deep neural network with 6 layers and a convolutional neural network gave the best results. Conclusions: This paper suggests that deep learning is an approach worth exploring further, however, with the disadvantage being that it requires large volumes of quality data.

Keywords: manufacturing, product lifecycle, management product failure, machine learning, prediction

JEL classification: C45, C53

Paper type: Case study

Received: Apr 23, 2020
Accepted: Jul 06, 2020

DOI: 10.2478/bsrj-2020-0014
Introduction

Todays’ business environment is highly competitive thus, businesses need to optimize their costs and improve their profit and/or market share. Warranty claim control, as a part of quality control department, is one of the most important departments since servicing warranties involves additional costs to the manufacturer. If warranty conditions are good that usually indicates higher product quality, thus affects marketing of new products (Murthy & Djamaludin, 2002). Higher quality of the product is related with product reliability which is, in a more technical definition, “the probability that the product (system) will perform its intended function for a specified time period when operating under normal (or stated) environmental conditions” (Blischke & Murthy, 2000, p.18). Even though a new product is usually tested before it is released to the public that does not necessarily mean that it will not malfunction under unusual circumstances. To alleviate problems of such scenarios, information about warranties can be used in order to monitor, warn (Lawless, 1998) and even to predict future events.

For warranty claims predictions, empirical models based on past data of products with experience-based correction factors are often used (Kljajić et al., 2000; Škraba et al., 2011; Wu et al., 2011; Dai et al., 2019). Nevertheless, many research in this field focuses on short-term forecasting, since reliable long-term forecasting is usually not possible due to the dataset they operate with. This research first extends previous research by providing new insight into possible machine learning models and second, provides additional understanding and validation on how data quality can affect those models.

In this paper, we set out to develop and validate a prediction model, using deep learning models on a case of a production-oriented company in the field of home appliances. We addressed the problem of improving the product failure forecasting process within the warranty period in the selected company, which has been, up to now, done “manually”, and mainly using spreadsheets in Microsoft Excel. The company was aware that the existing forecasting process was time-consuming, non-transparent and with many potential errors due to many manual data entries. As a result, there were discrepancies in the accuracy of the failure forecasts of individual products. Consequently, this means errors are being made in the reservation of funds to correct defects in products within the warranty period and that resulted as an oversupply of financial resources that cannot be used anywhere else in the company. Our main goal in this paper was to predict call rates 12 months into the future given up to 6 months of initial data for each series of product using machine learning methods.

Related work

When addressing problems that aim to forecast the future, we are talking about many different approaches such as time series, statistical models, simulation models and machine learning, more specifically predictive analytics. When using time series forecasting, we are collecting and analysing data from previous observations with the purpose of developing a model describing the underlying relationship between selected variables (Zhang, 2003). This kind of forecasting is convenient when there is little knowledge available on the underlying data. In the past researches, much effort has been devoted to the improvement of time series forecasting models. Kuremoto et al. (2014) for example proposes an improvement of multi-layer perceptron (MLP) and other artificial neural networks (ANNs) that had been used in time series since 1980s and replaces them using Hinton and Salakhutdinov’s deep belief nets (DBN) (Hinton,
Another example of upgrading time series to predict future is with the usage of statistical techniques such as Autoregressive Integrated Moving Average (ARIMA) – (Conejo et al., 2005; De Gooijer & Hyndman, 2006; Hyndman & Khandakar, 2008). To achieve better results with ARIMA, many authors, used or compared machine learning methods to improve predictions. Zhang (2003) described the use of hybrid ARIMA and neural network model that could be used for forecasting the next 12 months, whereas Valipour et al. (2013) compared ARIMA model with the autoregressive artificial neural networks (ANN) with forecasting abilities of 5 years in the future. Simulation models as another method for prediction of future events are focusing on the exploration and optimization of complex systems (Nyhuis et al., 2005). They represent a fairly complex system in a model that can be later applied to reality and often involve different kinds of forecasting, such as probabilistic and mechanistic modelling (Gujral et al., 2019).

Considering large amounts of data, many attributes and incomprehensible parameters, machine learning can be used to extract useful information from the dataset. Machine learning as such has played an important role in processing data, identification of data samples and in making decisions for the last couple of decades (Ge et al., 2017). Predictive analytics more specifically, has been used in many business applications such as customer relationship management, predicting crime-fighting in law enforcement, predicting warranty problems for automobile manufacturers, predicting change in stock price, etc. (Chan, 2007; Maričić et al., 2019). In the past few years, different methods for validating the reliability prediction model of electric products were used such as time series models and the ARIMA model, fuzzy methods, neural networks and expert systems (Li et al., 2010).

The problem addressed in this paper, prediction warranty call rates using some initial data for each production series, was previously addressed in (Kofjač et al., 2014). In Kofjač et al. (2014) authors used a combined model of market absorption and failure process, where forecasting activity for current products was done by using warranty claims for the first few months of service with the purpose of anticipating the final numbers of warranty returns while the warranty was still active. In general, there were two types of data. First type was focusing on products from sales to failure, and the other type was from production to failure, with the consideration of the market absorption time. For claims prediction, the authors proposed the Markov Modulated Fluid Model (Zhang, 1993). The model was verified and validated on the actual data and authors also proposed an application of grid computing due to costs of prediction in means of computational power (Kofjač et al., 2014).

In their later research Kofjač et al. (2016) proposed the use of machine learning methods for forecasting of terminal call rate (TCR), which is an expected maximum value of failed products within the warranty period (Kofjač et al., 2014). They investigated the impact of cumulative density function with ML models on TCR prediction accuracy which were modelled with exponential and logistic models. Their parameters were estimated with regression trees, neural networks and ensembles of regression trees. To evaluate goodness of fit of cumulative density functions, a standard error of the estimate (SEE) measure was used. The best results were achieved by ensembles of regression trees. Because the stance of the study was focused on fundamental research in the prediction of TCR with ML models, authors proposed future studies to improve the prediction accuracy, addressing the impact of other attributes, such as mean time to failure (MTTF) and the optimization of ML models, such as number of instances in leaves for regression trees.

Finally, the last research on the given problem was a project PKP (Po kreativni poti do znanja) funded under Public Scholarship, Development, Disability and Maintenance Fund of the Republic of Slovenia. The project addressed the falling
prices of processing and storage capabilities and the development of new models and techniques, where one could build models as needed using only the most relevant and recent data. The project aimed to develop the prototype application that would provide employees from the quality management department with call rate predictions for the next year to support planning of the expenses. In the core of this prototype was a stacked model that consisted of a linear regression model, a simple tree, and a random forest regressor. As new data was extracted from the transactional database it was transformed and stored as a matrix of cumulative call rates for each month following a production of an individual series. The model would then be applied to the user’s demand and it would locate the most appropriate date range and learn all three models on the provided data, followed by a modulation using the implementation of techniques from the Forecasting terminal call rate with machine learning methods (Koříč et al., 2016). This process was successfully implemented in the Guided Machine Learning for Business Users (Bourcevet et al., 2019). Models from PKP project would then vote on future predictions for series that are still in the warranty period. Their contribution would be weighted based on how well they performed on test inputs while learning. If prediction were triggered in the following months, when new data was available, the model would incorporate this data and re-learn itself before evaluating predictions for the new time. Given more data with each subsequent execution, the prototype should be less volatile and prone to errors (Arnerić et al., 2018), but this was never empirically tested on unseen data since the project ended before the prototype could be fully implemented and integrated with the transactional database.

This research contributes new findings based on related work, of how successful predictions in the field of warranty claims can be with the use of ML methods. Since both companies and customers can benefit from successful terminal call rate prediction, this research also contributes to practical aspect in terms of reserving more investment funds for company and getting more reliable products or faster and more efficient service procedures for customers.

Methodology

The proposed methodological approach is rooted in Design Science Research (DSR) (Hevner et al., 2004). The core of DSR represents the development cycle, in which an IT artefact is developed, in our case the ML predictive model. The development cycle is nested between the relevancy (real-life business problem), and rigor cycle, assuring scientific rigor by building on theory and prior knowledge. The development cycle follows the Cross-Industry Standard Process for data mining, CRISP-DM. The process or methodology of CRISP-DM is described in the six major steps: Business Understanding, Data Understanding, Data Preparation, Modelling, Evaluation and Deployment (Wirth & Hipp, 2000).

In the first two steps, business understanding and data understanding, we have studied previous research results of the warranty claim predictions (Koříč et al., 2014, 2016). Additionally, we have made several company visits, where we acquired new data and gained a deeper understanding of the business problem. The basic idea of gaining additional insight if another dimension to the data is added (Sašek, 2017).

The third step of the process refers to data preparation, which is usually the most time-consuming. Besides that, in this phase we gain new knowledge of the problem and data, so the first three steps are usually repeated in cycles until the desired result is achieved, that is the final data set.

The data was taken from the transactional database of all the service interventions. We received data for four specific markets - Nordic region, Germany, Russia and
Serbia. There were specifics for each market, which we were made aware of during our visits to the factory (for instance, it has been noticed that in the Nordic countries there is a greater time between the appliance failure and the service procedure than in other markets). Data was of varying quality depending on the market and the time in which it was produced. While newer data was more consistent, there was less of a systematic approach to gathering data in the past, thus limiting the usefulness of the data. Still, almost 50% of all service inquiries did not have the reason for failure listed and that was the important feature in our proposed models. Data preparation consisted of checking for inconsistent and missing data, which was then either cleaned or removed. The aim was to gain an insight into the relative number of failed appliances (within the first 6 months) and the reason for failure (387 unique reasons for failure). Next, we split the data based on the product hierarchy (product groups) and the country of manufacturing. The product hierarchy refers to the aggregation level of products, and allows us to analyse the TCR on different levels of detail (from groups of products to the specific product). It means that the product hierarchy PH5 has five identification numbers that go five levels in depth. If we take an example of kitchen appliances, we could say that PH1 represents kitchen appliances, PH2 cooling appliances, PH3 refrigerators and so on, until we can classify one product based on its colour. To provide enough training samples for neural networks, which require large quantities of data, we prepared separate matrixes for each market and we fragmented products based on a few different levels of product hierarchy provided by the data owner. This gave us 308 fragments on 4 markets for which we had data available for multiple series produced in the past. In total that gave us 11852 data points. We constructed upper triangular matrix, which is a square matrix where all the entries below the main diagonal are zero that contained TCR calculations. After that, we were able to proceed towards model development.

Our final model was a simple convolutional neural network with three convolutional layers and a fully connected layer. We were particularly interested in the performance of convolutional neural networks, given that we have a 2-dimensional dataset that has the same representation as a single-channel (grayscale) image. A Convolutional Neural Network (CNN) is a Deep Learning algorithm where learnable weights and biases are applied on the raw input image (Ji et al., 2013). CNN was recognized as a useful tool when, for example, enhancing reliability of software by predicting potential code defects in its implementation (Li et al., 2017), extracting useful clinical representations from longitudinal electronic health record data by predicting risks with CNN (Che et al., 2017) or for predicting instability mode in power system control (Shi et al., 2020).

We systematically approached hyper-parameter optimisation by running multiple neural networks with different configurations. We ran multiple permutations of the following parameters:

- Depth and type of neural networks: up to 6 hidden layers with varying number of neurons in each layer, convolutional neural network;
- Activation functions: ReLU, ELU, softmax, tanh and sigmoid function;
- Regularization: L2 normalisation and dropout with 50% dropout probability;
- Learning rate: starting with 0.1 and lowering it by order of magnitude with different configurations.

Using results from previous runs, we excluded some hyper-parameter configurations from the testing at researcher discretion in order to avoid combinatorial explosion.
Results

Our goal was to predict call rates 12 months into the future given up to 6 months of initial data for each series. First, we briefly present the business problem and data, which has already been discussed in (Kljajić et al., 2000; Kofjač et al., 2014, 2016; Škraba et al., 2011).

We received data in 56 different spreadsheets that varied in amount, features and purpose. Spreadsheets were classified in advance by the company experts for 4 specific markets. Data was gathered from service interventions, production and sales data. The complete dataset contained different features that were shattered across spreadsheets. List of features, its explanation and data type can be found in Table 1.

Table 1
Dataset features, explanation of features and their data type

<table>
<thead>
<tr>
<th>Feature name</th>
<th>Explanation</th>
<th>Data type</th>
</tr>
</thead>
<tbody>
<tr>
<td>No_OSS</td>
<td>Service intervention number</td>
<td>Numeric</td>
</tr>
<tr>
<td>Product_code</td>
<td>Unique identifier for a specific product</td>
<td>Numeric</td>
</tr>
<tr>
<td>Product_description</td>
<td>Description of a product</td>
<td>Text</td>
</tr>
<tr>
<td>Serial_number</td>
<td>Serial number of a product</td>
<td>Numeric</td>
</tr>
<tr>
<td>Date_manuf</td>
<td>Date of manufacturing</td>
<td>Date</td>
</tr>
<tr>
<td>Date_failure</td>
<td>Date of failure</td>
<td>Date</td>
</tr>
<tr>
<td>Date_purch</td>
<td>Date of purchase</td>
<td>Date</td>
</tr>
<tr>
<td>Date_repair</td>
<td>Date of repair</td>
<td>Date</td>
</tr>
<tr>
<td>Error_location</td>
<td>Descriptive location of the error</td>
<td>Text</td>
</tr>
<tr>
<td>Error_desc</td>
<td>Description of the error</td>
<td>Text</td>
</tr>
<tr>
<td>YearsOf_use</td>
<td>Number of years in use before failure</td>
<td>Numeric</td>
</tr>
<tr>
<td>Tech_nontech</td>
<td>Technical or nontechnical error identifier</td>
<td>Categorical</td>
</tr>
<tr>
<td>Brand</td>
<td>Brand of a product</td>
<td>Text</td>
</tr>
<tr>
<td>Work_order</td>
<td>Number of work order</td>
<td>Numeric</td>
</tr>
<tr>
<td>Error_type</td>
<td>Type of error</td>
<td>Text</td>
</tr>
<tr>
<td>Product_generation</td>
<td>Product generation (descriptive)</td>
<td>Text</td>
</tr>
<tr>
<td>Main_error</td>
<td>Description of a main error</td>
<td>Text</td>
</tr>
<tr>
<td>Graph_symb</td>
<td>Manufactured material for insertion part 1</td>
<td>Text</td>
</tr>
<tr>
<td>Graph_symb_2</td>
<td>Manufactured material for insertion part 2</td>
<td>Text</td>
</tr>
<tr>
<td>Inserted_mat_ID</td>
<td>Id of inserted material</td>
<td>Numeric</td>
</tr>
<tr>
<td>Inserted_mat_desc</td>
<td>Description of inserted material</td>
<td>Text</td>
</tr>
<tr>
<td>Buyer</td>
<td>Buyer of the product</td>
<td>Numeric</td>
</tr>
<tr>
<td>Seller</td>
<td>Seller of the product</td>
<td>Text</td>
</tr>
<tr>
<td>If_subgroup</td>
<td>Subgroup identifier</td>
<td>Text</td>
</tr>
<tr>
<td>Model_tag</td>
<td>Tag of a model</td>
<td>Text</td>
</tr>
<tr>
<td>Ph</td>
<td>8-digit unique designation based on product hierarchy</td>
<td>Numeric</td>
</tr>
<tr>
<td>Product_name</td>
<td>Name of the product</td>
<td>Text</td>
</tr>
<tr>
<td>Service</td>
<td>Name of repairer</td>
<td>Text</td>
</tr>
<tr>
<td>Type_tag</td>
<td>Tag of model type</td>
<td>Text</td>
</tr>
<tr>
<td>Material_kind</td>
<td>Description of material kind</td>
<td>Text</td>
</tr>
<tr>
<td>Material_type</td>
<td>Description of material type</td>
<td>Text</td>
</tr>
<tr>
<td>No_interventions</td>
<td>Number of interventions on a product</td>
<td>Numeric</td>
</tr>
<tr>
<td>Market</td>
<td>Market shortcode</td>
<td>Text</td>
</tr>
</tbody>
</table>

Source: Author’s work
Since data pre-processing pipelines are used to help automate machine learning workflows (Li, 2019), we had to rewrite them for the purpose of this new analysis. In previous research a dimension in a matrix first consisted of all products produced in a certain month and was now changed to a reason for failure. The result of this data preparation phase were matrixes, as presented in Figure 1, where the first dimension represents the error location and the second dimension represents the time from purchase to failure in months. We made a matrix for every product category in three different product hierarchies (PH3 – PH5) for every market. These matrixes were used as an input for our predictive models. Since the data in matrices on PH5 have duplicated values as ones on PH3 we got more data points we could use for our models. We used this solution to multiply training/testing instances because of the missing or inconsistent data. An example of the matrix with random data is represented in Figure 1.

Figure 1
New matrix as a result of pre-processing pipeline

<table>
<thead>
<tr>
<th>Error location</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Error 1</td>
<td>8</td>
<td>8</td>
<td>16</td>
<td>5</td>
<td>4</td>
<td>16</td>
<td>12</td>
<td>4</td>
<td>7</td>
<td>10</td>
<td>9</td>
<td>5</td>
</tr>
<tr>
<td>Error 2</td>
<td>10</td>
<td>14</td>
<td>5</td>
<td>1</td>
<td>15</td>
<td>6</td>
<td>18</td>
<td>18</td>
<td>6</td>
<td>15</td>
<td>15</td>
<td>19</td>
</tr>
<tr>
<td>Error 3</td>
<td>18</td>
<td>5</td>
<td>16</td>
<td>6</td>
<td>18</td>
<td>9</td>
<td>3</td>
<td>20</td>
<td>17</td>
<td>16</td>
<td>6</td>
<td>9</td>
</tr>
<tr>
<td>Error 4</td>
<td>12</td>
<td>18</td>
<td>20</td>
<td>16</td>
<td>3</td>
<td>14</td>
<td>4</td>
<td>18</td>
<td>19</td>
<td>16</td>
<td>1</td>
<td>7</td>
</tr>
<tr>
<td>Error 5</td>
<td>17</td>
<td>13</td>
<td>11</td>
<td>18</td>
<td>9</td>
<td>17</td>
<td>9</td>
<td>10</td>
<td>4</td>
<td>14</td>
<td>4</td>
<td>14</td>
</tr>
<tr>
<td>Error 6</td>
<td>4</td>
<td>8</td>
<td>16</td>
<td>18</td>
<td>10</td>
<td>7</td>
<td>7</td>
<td>16</td>
<td>9</td>
<td>2</td>
<td>8</td>
<td>9</td>
</tr>
<tr>
<td>Error 7</td>
<td>19</td>
<td>10</td>
<td>12</td>
<td>16</td>
<td>2</td>
<td>17</td>
<td>4</td>
<td>14</td>
<td>19</td>
<td>2</td>
<td>17</td>
<td>3</td>
</tr>
<tr>
<td>Error 8</td>
<td>17</td>
<td>18</td>
<td>20</td>
<td>10</td>
<td>18</td>
<td>9</td>
<td>7</td>
<td>16</td>
<td>2</td>
<td>5</td>
<td>13</td>
<td>4</td>
</tr>
<tr>
<td>Error 9</td>
<td>9</td>
<td>1</td>
<td>20</td>
<td>1</td>
<td>11</td>
<td>19</td>
<td>8</td>
<td>2</td>
<td>7</td>
<td>15</td>
<td>13</td>
<td>4</td>
</tr>
<tr>
<td>Error 10</td>
<td>4</td>
<td>7</td>
<td>9</td>
<td>3</td>
<td>20</td>
<td>6</td>
<td>20</td>
<td>2</td>
<td>5</td>
<td>12</td>
<td>14</td>
<td>16</td>
</tr>
<tr>
<td>Error 11</td>
<td>20</td>
<td>6</td>
<td>7</td>
<td>3</td>
<td>8</td>
<td>1</td>
<td>15</td>
<td>4</td>
<td>18</td>
<td>2</td>
<td>12</td>
<td>14</td>
</tr>
<tr>
<td>Error 12</td>
<td>10</td>
<td>7</td>
<td>16</td>
<td>12</td>
<td>11</td>
<td>16</td>
<td>8</td>
<td>13</td>
<td>6</td>
<td>8</td>
<td>18</td>
<td>10</td>
</tr>
<tr>
<td>Error 13</td>
<td>7</td>
<td>4</td>
<td>4</td>
<td>9</td>
<td>16</td>
<td>7</td>
<td>13</td>
<td>7</td>
<td>17</td>
<td>19</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Error 14</td>
<td>5</td>
<td>3</td>
<td>15</td>
<td>2</td>
<td>6</td>
<td>11</td>
<td>8</td>
<td>3</td>
<td>10</td>
<td>16</td>
<td>14</td>
<td>2</td>
</tr>
<tr>
<td>Error 15</td>
<td>8</td>
<td>18</td>
<td>19</td>
<td>16</td>
<td>11</td>
<td>13</td>
<td>2</td>
<td>14</td>
<td>12</td>
<td>14</td>
<td>8</td>
<td>9</td>
</tr>
<tr>
<td>Error 16</td>
<td>13</td>
<td>14</td>
<td>5</td>
<td>12</td>
<td>15</td>
<td>16</td>
<td>19</td>
<td>20</td>
<td>18</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Error 17</td>
<td>12</td>
<td>20</td>
<td>11</td>
<td>16</td>
<td>4</td>
<td>12</td>
<td>8</td>
<td>20</td>
<td>18</td>
<td>9</td>
<td>1</td>
<td>19</td>
</tr>
<tr>
<td>Error 18</td>
<td>16</td>
<td>1</td>
<td>14</td>
<td>8</td>
<td>19</td>
<td>14</td>
<td>8</td>
<td>4</td>
<td>17</td>
<td>12</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Error 19</td>
<td>10</td>
<td>13</td>
<td>19</td>
<td>18</td>
<td>9</td>
<td>11</td>
<td>14</td>
<td>12</td>
<td>5</td>
<td>2</td>
<td>5</td>
<td>12</td>
</tr>
<tr>
<td>Error 20</td>
<td>6</td>
<td>5</td>
<td>20</td>
<td>18</td>
<td>1</td>
<td>19</td>
<td>1</td>
<td>3</td>
<td>12</td>
<td>17</td>
<td>11</td>
<td>7</td>
</tr>
<tr>
<td>Error 21</td>
<td>1</td>
<td>19</td>
<td>8</td>
<td>2</td>
<td>13</td>
<td>20</td>
<td>9</td>
<td>13</td>
<td>11</td>
<td>7</td>
<td>17</td>
<td></td>
</tr>
<tr>
<td>Error 22</td>
<td>1</td>
<td>17</td>
<td>12</td>
<td>20</td>
<td>17</td>
<td>6</td>
<td>18</td>
<td>2</td>
<td>4</td>
<td>7</td>
<td>17</td>
<td>2</td>
</tr>
<tr>
<td>Error 23</td>
<td>14</td>
<td>19</td>
<td>11</td>
<td>13</td>
<td>11</td>
<td>4</td>
<td>9</td>
<td>20</td>
<td>6</td>
<td>16</td>
<td>13</td>
<td>20</td>
</tr>
</tbody>
</table>

Source: Author’s work

Upon inspection of this previously unused dimension of the data, we learned that there are a lot of missing values. More than 46% of the service entries had no stated reason for the failure. This was varying from market to market, for example, the Serbian market being the worst and German being the best, which suggested that we could possibly extract useful data from certain markets while the model would pay less attention to the markets with a lot of missing data, presented in Figure 2.
Before using ANN, Kofjač et al. (2014) applied Markov Modulated Fluid model (MMFM) that achieved a prediction accuracy of 0.79 at best. Kofjač et al. (2014) also proposed the use of other methods such as grid computing due to the computationally costly prediction of MMFM. In their later research, Kofjač et al. (2016) used ML methods (regression tree, feedforward neural network and ensemble of regression trees) to estimate a real-valued variable TCR where input pattern of cumulative failure rates was given. The highest prediction accuracy was given when they used an ensemble of 100 regression trees, with the average mean absolute percentage error (MAPE) of 2.31%. Ensemble learning in that case provided the best results because of the diversity of features and that, along with non-linear characteristics of cumulative density function, which is used to predict TCR, was the reason for using ANN. In addition, since traditional forecasting models have limitations with considering non-linear relationships, ANNs on the other hand, can provide a robust alternative to model and extract unseen features and relationships. In addition, ANN’s do not impose any restriction on input and residual distributions.

We generated three different models - a perceptron (which was scrapped immediately since it did not converge), a few variations of deep neural networks and a convolutional neural net. As expected, perceptron did not converge after 100 epoch, since a single layer network is suited for solving simple linear problems, and not, as in our case, more complex non-linear problems.

Further, we optimized the neural network by adding hidden layers, adjusting the number of neurons at each level, applying different activation functions, and regularizations. We used L1 norms+ (absolute difference) to measure accuracy since...
it is most intuitively interpreted by human experts (or users of predictions), in the QA department.

We tested the variations from 1 to 6 hidden layers with variations of number of neurons at each level from 2048, 1024, 512, 256, 128, and 64. For activation function, the sigmoid function was used. The results of learning did not converge after 100 epochs. In fact, the results of various deep neural networks, applying various combinations of layers and neurons, did not defer from the perceptron. Further analysis into the modelled data have shown that there are missing data because of the delay of the market absorption (i.e. no sale is recorded for 6 months, thus the matrix for months 1 to 6 are empty). To address this problem, we have cleaned out the empty data matrices and trained the multilayer NN again. Comparison of convergence of the single layer (orange coloured curve) and the multilayer layer NN (blue and purple coloured curves) is shown in Figure 3. It can be observed that the convergence is faster with the multilayer NN, but needs more time to reach the stable value (the multiple NN stabilizes at 900 seconds of training, while the single layer at 440 seconds).

Our final model was a simple convolutional neural network with three convolutional layers and a fully connected layer. It also incorporated regularization techniques from previous examples. We generated three different models - a single layer perceptron (which was scrapped immediately since it did not converge), a few variations of deep neural networks and a convolutional net. We used L1 norms+ (absolute difference) to measure accuracy since it is most intuitively interpreted by humans that would look at the results (QA department in the selected company). With starting learning speed of 0.101 and prediction accuracy from 0.3 to 0.4, depending on the series, there was no significant difference between a deep neural network and convolutional networks in terms of accuracy but the convolutional network did converge faster, which could mean shorter learning times with less computing resources as can be observed in Figure 3. It can be observed that the convergence is faster with the multilayer NN, but needs more time to reach the stable value (the multiple NN stabilizes at 900 seconds of training, while the single layer at 440 seconds).

**Figure 3**
Convergence of learning of single and multilayer NN (6 hidden layers)

![Convergence of learning of single and multilayer NN (6 hidden layers)](image)

Source: Adapted from Sašek (2017)

Further, we tested how various activation functions contribute to performance (convergence time and accuracy). We tested Sigmoid (shown in Figure 3), ReLu, ELU, and tanh. The prediction accuracy had improved slightly with using ELU function shown in Figure 4.
Figure 4
Convergence of learning with the use of ELU function. Comparing simple (orange) and multilayer NN with 6 hidden layers (purple)

Source: Adapted from Sašek (2017)

Figure 5 compares a simple NN, represented with orange, with a multilayer NN, in purple, where results indicate that the error remains the same as with simpler model when we used Tanh activation function.

Regularization is normally used to address the problem of overfitting to training data. In our case overfitting was not the problem, but we still wanted to test how it will affect the performance of the model, since the data is asymmetrical. We applied two methods: dropout and L2 regularization. Dropout addresses the problem of slow speed of large networks, which makes dealing with overfitting during training of NN difficult (Srivastava et al., 2014). It randomly drops units from the NN during training, thus preventing overfitting. L2 regularization on the other hand updates the general cost function by adding regularization term were the weight values are pulled towards zero, therefore a smaller weight matrices lead to simpler models which are easier to train (Phaisangittisagul, 2016). None of the regularization techniques contributed to performance quality, the prediction accuracy was even decreased.

Figure 5
Convergence of learning with the use of tanh function. Comparing simple (orange) and multilayer NN with 6 hidden layers (purple)

Source: Adapted from Sašek (2017)

Figure 6 shows convergence of learning of the convolutional neural network (in red) and the fully connected neural network (in green) with 8 layers (6 hidden layers, input and output layer) with learning rate 0.0101. Number of neurons in hidden layers are presented in Table 2.
Figure 6
Convergence of learning of the convolutional neural network (in red) and fully connected neural network (in green)

Source: Adapted from Sašek (2017)

Table 2
Number of neurons in hidden layers in fully connected neural network

<table>
<thead>
<tr>
<th>Hidden layer</th>
<th>Number of neurons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hidden layer 1</td>
<td>2048</td>
</tr>
<tr>
<td>Hidden layer 2</td>
<td>1024</td>
</tr>
<tr>
<td>Hidden layer 3</td>
<td>512</td>
</tr>
<tr>
<td>Hidden layer 4</td>
<td>256</td>
</tr>
<tr>
<td>Hidden layer 5</td>
<td>128</td>
</tr>
<tr>
<td>Hidden layer 6</td>
<td>64</td>
</tr>
</tbody>
</table>

Source: Author’s work

Figure 7 represents convergence of learning of convolutional neural network (in red) and the fully connected neural network (in green) with 8 layers (6 hidden layers, input and output layer). Learning rate presented on the Figure 7 was changed to 0.101.

With the starting learning rate of 0.101 and MAPE from 0.3 to 0.4, depending on the series, there was no significant difference between a deep neural network and a convolutional network in terms of accuracy, but the convolutional network did converge faster, which could mean shorter learning times with less computing resources.

Figure 7
Convergence of learning of convolutional neural network (in red) and fully connected neural network (in green) with higher learning rate (0.101)

Source: Adapted from Sašek (2017)
During this stage, we managed to reduce the window of prediction from 36 or 60 to 12 months while maintaining to support the business needs of the company. This new window of prediction enables company to gather less data for the same prediction power which means that they can predict future events three times faster than before.

**Conclusion**

The problem of call terminal rate prediction for home appliances manufacturing was addressed. In our previous studies, we have tried out different approaches (hybrid models based on discrete and continuous simulation, time series) with little success. In the light of the popularity of machine learning predictive models, new insights and data, we set out to develop the predictive model using deep learning. We employed the CRISP-DM process, learning about business requirements, understanding the data and putting a lot of work into cleaning the data and transforming it into the right format for consumption by neural nets. After that, we developed a few predictive models based on different neural network architectures. The main limitation of our research was the amount and quality of data, which proved to be of issue in training the models.

The results showed that the best two models, deep neural network with 6 layers and a convolutional neural network differed in 1% when predicting TCR at 12 months. The lowest error of prediction was in the range between 30 and 40%, thus being too high and not better than the methods company is currently using. Based on these results we could not conclude that deep neural networks perform better or worse than conventional ML methods for prediction of call rates in home appliances. What we could conclude is that the main factor for performance of our models was inconsistency and quality of our data.

The main contribution of the paper is in the application of deep learning models on a real-life industry case, displaying how standardized, complete and comprehensive data is of great importance in leveraging any kind of predictive analytics. Previous research provided beneficial results for the company based on literature review, nevertheless, there wasn’t much research done on using deep learning for the same business problem. Since we had the opportunity to gather more data than previous researchers (Kofjač et al., 2014, 2016), therefore we could extend previous research by providing new models and findings on addressing terminal call rate prediction.

Our study as well as several others (Wu et al., 2011; Ge et al., 2017; 5. Bourcevet et al., 2019; Dai et al., 2019) corroborate the importance of data quality and the data preparation process. Data quality and quantity was the biggest limitation of our work, since deep learning method need large datasets to train the models, and the models are only as good as the input data is. In the future, more effort should be put to quality data gathering, for researchers as well as businesses. Only with quality data we will be able to examine the effect of neural networks and other machine learning methods (Deep belief networks, LSTM networks, recursive networks, etc.). Furthermore, as suggested by (Bohanec et al., 2017a, 2017b), explainability and transparency of predictive models can contribute to better user involvement, which is important for quality data gathering. Not only the predictive power of the models, but also understanding the predictions, especially which attributes or combination of attributes can contribute to the product failure, is important.
References
About the authors

Aljaž Ferencek is a doctoral student at the Faculty of Organizational Sciences at the University of Maribor. He received his master's degree at the same faculty from information systems studies. His research interests include data science, prediction analytics and open government data. He has already published some scientific articles on this subject. The author can be contacted at aljaz.ferencek@student.um.si

Davorin Kofjač obtained his PhD from the University of Maribor in the field of information systems management. He is a researcher and an associate professor at the University of Maribor, Faculty of Organizational Sciences, in the Cybernetics and Decision Support Systems Laboratory. His main research interests are modeling and simulation, decision-support systems, operational research, and artificial intelligence. He has been involved in many EU, NATO, bilateral, and national projects and is the author of more than 120 publications in international journals, monographs, and conferences. He is a member of ACM, INFORMS, and SLOSIM. The author can be contacted at davorin.kofjac@um.si

Andrej Škraba obtained his PhD in the field of organizational sciences–informatics from the University of Maribor. He works as a full professor and a researcher in the Cybernetics & Decision Support Systems Laboratory at the Faculty of Organizational Sciences, University of Maribor. His research interests cover systems theory, modeling and simulation, cyber-physical systems, and decision processes. His work has been published in the following peer-reviewed journals: Simulation, System Dynamics Review, Journal of Mechanical Engineering, Computers and Electronics in Agriculture, Kybernetes, Interfaces, and Group Decision and Negotiation. He is a member of System Dynamics Society and SLOSIM. The author can be contacted at andrej.skraba@um.si

Blaž Sašek is a master's student at University of Maribor, Faculty of Organizational Sciences, where he studies information systems. He is most interested in data science, focusing mainly on machine and deep learning. The author can be contacted at blaz.sasek@student.um.si

Mirjana Kljajič Borštnar received her Ph.D. in Management Information Systems from the University of Maribor. She works as an Associate Professor at the Faculty of Organizational Sciences, University of Maribor and is a member of Laboratory for Decision Processes and Knowledge-Based Systems. She has been involved in many EU and national projects. Her research work covers data-driven decision support systems, data mining, multi-criteria decision-making, and organizational learning. She co-authored several scientific articles published in recognized international journals, including Expert Systems with Application, PLOS ONE, and Industrial Management & Data Systems. She is a editorial board member of Uporabna informatika journal, program committee member of Bled eConference, DataScience conference, International Symposium on Operations Research in Slovenia, and research representative in national Strategic Research & Innovation Partnership Smart Cities and Communities for Artificial Intelligence. The author can be contacted at mirjana.kljajic@um.si
Process Mining Contributions to Discrete-event Simulation Modelling

Mario Jadrić
University of Split, Faculty of Economics, Business and Tourism, Split, Croatia
Ivana Ninčević Pašalić
University of Split, Faculty of Economics, Business and Tourism, Split, Croatia
Maja Ćukušić
University of Split, Faculty of Economics, Business and Tourism, Split, Croatia

Abstract

Background: Over the last 20 years, process mining has become a vibrant research area due to the advances in data management technologies and techniques and the advent of new process mining tools. Recently, the links between process mining and simulation modelling have become an area of interest. Objectives: The objective of the paper was to demonstrate and assess the role of process mining results as an input for discrete-event simulation modelling, using two different datasets, one of which is considered data-poor while the other one data-rich. Methods/Approach: Statistical calculations and process maps were prepared and presented based on the event log data from two case studies (smart mobility and higher education) using a process mining tool. Then, the implications of the results across the building blocks (entities, activities, control-flows, and resources) of simulation modelling are discussed. Results: Apart from providing a rationale and the framework for simulation that is more efficient modelling based on process mining results, the paper provides contributions in the two case studies by deliberating and identifying potential research topics that could be tackled and supported by the new combined approach. Conclusions: Event logs and process mining provide valuable information and techniques that could be a useful input for simulation modelling, especially in the first steps of building discrete-event models, but also for validation purposes.

Keywords: process mining, event log, simulation model, smart mobility

JEL classification: M15
Paper type: Research article

Received: Feb 3, 2020
Accepted: Apr 24, 2020

Acknowledgements: This research is supported by the Croatian Science Foundation [grant number UIP-2017-05-7625].

DOI: 10.2478/bsrj-2020-0015
Introduction

Process mining (PM) is a relatively new scientific domain; as organisations needed to learn more about how their processes function in the real world, concepts and tools related to business process mining emerged (Tiwari et al., 2008). The advent of PM was characterized by different algorithmic approaches concentrating on log data. For example, Agrawal et al. (1998) constructed a process flow graph from execution logs of a workflow application. At the same time, Cook and Wolf (1998) attempted to discover the process models from event log data. Van Der Aalst et al. (2004) affirmed the importance of transactional information systems that can provide appropriate (log) data. PM derived from data mining, referring specifically to the extraction of knowledge from large data sets by identifying patterns within data (Tiwari et al., 2008). As an adaption of data mining, PM is defined as a methodology for obtaining process models from event logs associated with particular processes (Van Der Aalst, 2011).

To achieve the objectives set at the individual and institutional level, organisations focus on improving their business processes. Simulation modelling (SM) has helped in understanding the complexity of business processes, although the main challenge remained to be the development of a realistic simulation model. With technological advances, business processes are increasingly supported by information systems that generate event logs (Abohamad et al., 2017). The logs contain important information about the actual performance of a process and can be analysed using process mining techniques (Van Der Aalst, 2011). Consequently, PM techniques help gain new insights, which can prove to be beneficial as an input in conceptual simulation modelling stages. The output of PM is a process model consisting of a set of activity models and constraints between them (Weske, 2012). Relation and relevance of the model in the context of simulation modelling is the focus of the paper.

The rising number of publications in the Web of Science and Scopus databases for “process mining” AND “simulation” is noteworthy, clearly indicating the emerging research trend in the area studied since 2012. Despite a growing number of studies that relate the benefits of coupling process mining with simulation modelling, the research area still has some challenges that need addressing (Van Der Aalst, 2012; Zakarija et al., 2020). Therefore, this exploratory study aims to address particular scientific challenges noted by the IEEE’s Task Force (2011) and to demonstrate the relevance of process mining in specific settings. In consideration of specific challenges identified in PM manifesto (IEEE TFPM, 2011) related to finding/merging/cleaning event data, handling event logs with different characteristics and combining process mining with other types of analysis, the following research questions were formulated in this study:

**RQ1:** How different sets of event data and event logs affect process mining results?
**RQ2:** How useful is a combination of process mining with other types of analysis, in particular - how PM results perform as input for discrete-event simulation modelling?

Therefore, the objective of the paper is to demonstrate and assess the potential of using process mining results as an input for discrete-event simulation modelling. The process mining procedure is elaborated using two datasets in two different domains, of which one dataset is considered as data-poor (smart parking) and the other one data-rich (learning management system).

The paper is organised as follows. Chapter 2 presents an overview of key concepts, including PM types, techniques, event logs, and linking PM with discrete-event SM. Chapter 3 outlines and discusses the methodology of the exploratory study, including quantitative and qualitative analyses of cases in two different domains. Chapter 4 discusses the results of the study by comparing it with existing research, explains
contributions to the research area, and puts forward implications for the practice. Chapter 5 concludes the study, lists the limitations and suggestions for future research.

Theoretical background

Process mining types and techniques

According to Van Der Aalst et al. (2010), there are three basic types of business process mining: 1) Process discovery where there is no a priori model, i.e. a process model is discovered from an event log without prior knowledge of the process itself; 2) Conformance checking where a priori model for a process is known and is used for detecting, locating and explaining possible deviations from the standard process (Rovani et al., 2015); and (3) Extension where a priori model is known, and it is improved by further data adding a new perspective. Later, Van Der Aalst (2011) replaced the third type of PM with a new term – enhancement, denoting two different types of enhancement: repair (aiming to modify the model to reflect the reality better) and extension (adding a new perspective to the process model). Generally, three perspectives in business process mining are highlighted (Dustdar et al., 2005): 1) process perspective where the aim is to find a suitable representation of all possible paths within the process; 2) organisational perspective, which focuses on people, their roles and their relationships; and 3) case perspective that considers attributes that differentiate one process (case) path from the other. Similarly, Van Der Aalst (2011) distinguishes between four perspectives of PM application: 1) control-flow perspective where the focus is on process structure discovery (“How?”), 2) organisational or resource perspective focusing on resource information (“Who?”), 3) case/data perspective focusing on properties of cases (“What?”), and 4) time perspective related to the timing and frequency of events (“When?”).

With regards to business process mining techniques, Turner et al. (2012) list five categories: 1) Transition systems and regions – a technique that mines the models that offer a balance between over- and under-fitting the event log (Van Der Aalst et al., 2010); 2) Clustering techniques - techniques that provide the possibility to combine different process mining approaches in order to mine more challenging event logs, e.g. those containing noise; 3) Heuristic approach – an approach set by Weijters and Van Der Aalst (2001, 2003) who established a set of rules to determine the precedence between tasks and overall task sequences; 4) Evolutionary techniques (such as genetic algorithm by de Mederios et al. (2005) aimed to mine logs containing noise and duplicate tasks); 5) Declarative mining approach suggested by Cattafi et al. (2010) that recognises that the changes in process are possible over time, and revisions of the mined model will take into account new process evidences and deviations. Focusing on PM techniques used for control-flow discovery exclusively, Rojas et al. (2016) emphasised that the most frequently used PM techniques are: 1) Heuristics Miner which successfully deals with noise in event logs thus generating strong business process models (Weijters et al., 2006); 2) Fuzzy Miner which can generate multiple process control models based on fuzzy criteria; and 3) Trace Clustering techniques that can discover simple process models by dividing into partitions (Song et al., 2009).

In their review study, Tiwari et al. (2008) analysed the main techniques used for PM concluding that in 39% of the reviewed papers authors developed custom algorithmic approaches to process mining, while in 10% of papers authors used data mining-based approaches, 6% used soft computing techniques for the process-mining tasks, and in 29% of reviewed papers authors detailed the use of Petri net modelling.

With the growing popularity of the concept, the tools for PM were developed: Disco (by Fluxicon), ARIS Process Performance Manager (by Software AG), Perceptive
Process Mining (by Perceptive Software), Celonis Process Mining (by Celonis GmbH), Process Analyzer (by QPR), Interstage Process Discovery (by Fujitsu), Discovery Analyst (by Stereo LOGIC), and XMAnalyzer (by XMPro) to list the most important ones.

**From event data to event logs**

Event logs are sets of traces where each trace describes the lifecycle of a particular case (i.e., a process instance) in terms of the activities executed, resources engaged for completing the activity, timestamp, and other information (Van Der Aalst, 2015). A simple example of an event is presented in Table 1.

<table>
<thead>
<tr>
<th>Case id</th>
<th>Timestamp</th>
<th>Activity</th>
<th>Resource</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>123456</td>
<td>30-12-2019:11.02</td>
<td>register request</td>
<td>John</td>
<td>1000</td>
</tr>
</tbody>
</table>

Source: Authors’ example

In this context, the problems of incomplete and raw data often occur, and to deal with this particular issue authors attempted to review and broaden the definition of events. Events are described by references and attributes where references designate a name of an object (for example a person, machine, product), while attributes can denote a name, value, and can contain perspectives like time, age, function, or category (Van Der Aalst, 2015; Wang, 2018). Relevant guidelines for data logging, set by Van Der Aalst (2015) include: 1) precise semantics of reference and variable names as they should have the same meaning for all stakeholders, 2) reference and variable names should be recorded in a structured and managed collection, 3) references should be stable, and independent to different identifiers, 4) attribute values should be precise, 5) occurrence, references or attributes of the events should be clearly marked in cases of uncertainty, 6) events should be ordered, if possible, using the timestamp variable, 7) transactional information about an event should be stored, 8) syntax correctness of the event log should be checked regularly, 9) comparability of event logs needs to be ensured, 10) events should be detailed and not aggregated in the event log which will be an input to the analysis process, and 11) events should not be deleted. Wang (2018) added additional four guidelines as a part of the D2FD (Data to Fuzzy-DEVS) method: 12) privacy should be ensured without losing correlations, 13) event data should be recorded in .csv format or excel files, 14) value names should be simple and clear, 15) the start time and the finish time in the attribute properties are mandatory. The same author complements the list with a general recommendation to 16) order events by instance and then by start date (where instance defines a specific sequence of a case, and a reference is identified as a label of instance).

Creating an event log from raw event data consists of the following steps (Van Der Aalst, 2015): 1) selecting relevant events for the process at hand, 2) correlating events to form process instances, 3) ordering the events using timestamp information, and 4) selecting or computing event attributes based on the raw data (resource, cost, and more). Similarly, Wang (2018) proposed a five-step method to transform the event data to event logs: 1) defining the goal – the first step of the method implies addressing the problem and determining the purpose of performance evaluation, 2) identifying the relationships which can help researchers in finding the analysis results, 3) identifying the values, 4) selecting the process instance, and 5) mapping between event data and event logs.
From process mining to discrete-event simulation modelling

New studies emerged, describing attempts to integrate process mining techniques with simulation modelling. As this is an area to which this paper aims to contribute to, this section provides a brief overview of the work done in that regard.

Martin et al. (2015) presented their conceptual model of how PM techniques can be used to support the construction of simulation models. They used an illustrative case study with a company that provides roadside assistance services to demonstrate that the combination of event log knowledge and traditional information sources (expert interviews) is complementary in the process of constructing a simulation model. Abohamad et al. (2017) presented a framework for integrating process mining techniques into the conceptual modelling phase, i.e. in one of the steps in developing simulation models. The proposed hybrid framework was then tested to determine the performance bottlenecks and explore possible improvement strategies within a hospital’s emergency department. In the same application domain - health, Zhou et al. (2014) tried to combine process mining with simulation models to develop an outpatient clinic model. A more general approach was proposed by Rozinat et al. (2009) where the authors developed a simulation model presented as a Coloured Petri Network (CPN) for process analysis and performance evaluation of different models. The authors used a combination of process mining techniques to detect control-flow, data, performance, and process resources based on historical data, and integrated them into the CPN simulation model. Another recent use case was presented by Jadić (2019), focusing on possible issues and advantages of the detection of student behaviour and processes based on the data from a standard learning management system. He then proposed a conceptual model for using process mining techniques to support the development of discrete-event simulation models in an educational environment.

Discrete-Event Simulation (DES) in this paper denotes multiple computer simulation approaches based on the general idea of modeling a state of a discrete dynamic system which is composed of “state variables” provided by the attributes of “entities” which represent real objects (Wagner et al., 2016). Modelling the system dynamics is done through modelling the events that are reflective of system state changes (ibid). In that context, an event is considered as something that triggers the next set of state variable changes (Liu, 2015). Discrete-event modelling process generally progresses through several steps (illustrated in Figure 1).

A brief outline of the illustrated steps is provided herein: 1) data collection - following standard sampling practices to collect data on the real system in a representative way, 2) random number generation - used to generate a set of random numbers for an input model, 3) determining the input model - to transform a set of random numbers into a set of input data based on the selected statistical distribution; the transformation process is called the generation of random variables, 4) development of conceptual and computational models and their verification, 5) analysis of the output generated by the use/deployment of a computational model based on a set of input data for model validation, and 6) statistical analysis of output data, including, for example, calculating mean, median, standard deviation and confidence intervals, and then experimenting using the simulation model.
To discrete-event modelling process, event logs and process mining can provide valuable information and techniques that could be used for simulation modelling, especially in the first steps of building discrete-event models. The potentials and the extent of the use of event logs in building simulation models are elaborated by Martin et al. (2015) for each of the aggregated simulation model building blocks: entities, activities, control-flow, and resources. Table 2 provides an overview of the role of process mining in simulation modelling by matching aggregated building blocks to relevant process mining features.

Table 2
Overview of PM Research Contributions in Simulation Modelling

<table>
<thead>
<tr>
<th>Model component</th>
<th>Modelling task</th>
<th>Process mining contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entities</td>
<td>Entity attributes</td>
<td>After the appropriate mapping of case and event attributes to entity attributes is ascertained, logs are used to analyse and assign attribute values to entities.</td>
</tr>
<tr>
<td></td>
<td>Entity type</td>
<td>The authors have not identified examples and research efforts to support entity type modelling using event logs. However, the potential is evident, considering different event log information that is frequently recorded.</td>
</tr>
<tr>
<td></td>
<td>Entity arrival date</td>
<td>Actual entity arrival is critical information as it has a significant influence on the process performance (e.g., the average queue length). This information can usually be extracted from event logs.</td>
</tr>
</tbody>
</table>
Activities

<table>
<thead>
<tr>
<th>Activity definition</th>
<th>Event logs can be helpful when defining simulation model activities since, by definition, activities record events in the log; however, particular focus should be put on the fact that event logs might register even more detailed information (Baier et al., 2013).</th>
</tr>
</thead>
<tbody>
<tr>
<td>Activity duration</td>
<td>Due to an extensive array of activity duration determinants (Pospišil &amp; Hruška, 2012), their modelling is complex. However, the duration can be determined from the logs as the difference between the timestamps of start and end events.</td>
</tr>
<tr>
<td>Resource requirements</td>
<td>PM is only useful in this regard if an event log contains resource information.</td>
</tr>
<tr>
<td>Queue discipline</td>
<td>Authors acknowledge there is little research done in analysing topics related to queuing despite the PM potential.</td>
</tr>
<tr>
<td>Queue abandonment condition</td>
<td>Potential to explore the topic is enormous as event log registers the abandonment as well.</td>
</tr>
<tr>
<td>Interruptibility and unexpected interruptions</td>
<td>A combination of outlier analysis and log-based resource schedules can support the identification of interruptible activities.</td>
</tr>
</tbody>
</table>

Control-Flow

<table>
<thead>
<tr>
<th>Control-flow definition</th>
<th>PM provides the most extensive support for control-flow discovery as the sequential relationship between activities, and gateway type can be discovered by analysing log data.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gateway routing logic</td>
<td>Event logs can support modelling of routing logic by analysing circumstances of activity execution such as the probabilities and frequencies of different activity routes.</td>
</tr>
</tbody>
</table>

Resources

<table>
<thead>
<tr>
<th>Resource roles</th>
<th>Event logs contain resource information that can support resource role identification.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resource schedule</td>
<td>Event log analysis for resource scheduling is complicated; however, it can be helpful in some cases.</td>
</tr>
<tr>
<td>Unavailability handling procedure</td>
<td>This aspect can be handled as a part of the research on the discovery of resource schedules.</td>
</tr>
<tr>
<td>Entity handling procedure</td>
<td>An analysis of the activities performed by a resource is required when modelling entity handling procedure using event logs.</td>
</tr>
</tbody>
</table>

Source: Adapted from Martin et al. (2015)

Methodology

This part of the paper describes the methodology used to address research questions set in the introductory section. First, background information is provided based on the literature review for both domains of the case studies (the first one from smart mobility area and the second from the higher education). After that, the rationale for selecting the case studies is presented, followed by a description of PM procedures and
analyses where RQ1 is addressed i.e. how different sets of event data and event logs affect process mining results. Then, the role of process mining in building simulation models is assessed by considering aggregated building blocks (entities, activities, control-flow, and resources) given the results of the case studies, presenting the answer to RQ2.

Two different datasets have been used for process mining and imported into Disco process mining. The software enables automatic discovery of process models based on imported data using optimised high-speed process discovery algorithm. The tool is available from https://fluxicon.com/disco/. Resulting process maps are intuitive and easy to work with, and the software enables dynamic process overview (lapse of time can also be animated using the model). The tool provides extensive reporting features, and a great number of process maps can be generated, however, due to page limit, only several are selected to be presented in the analysis. A downside is that the rendered maps cannot be easily customised, consequently being hard to read.

Background: process mining in smart mobility and higher education

Smart mobility

Popular use case in the smart city domain is the implementation of smart parking solutions, which contributes to the optimisation of peoples' time, reduction of fuel consumption and carbon dioxide emissions (Barriga et al., 2019). The architecture of smart parking solutions is frequently characterised by three components - sensors, communication protocols, and software solutions (ibid). As a part of the literature review, the keyword search has been conducted in the Scopus database to review the state-of-art of process mining in smart mobility, but no results have been found filtering the title option. An additional check has been done to explore whether any other type of mining has been discussed in the smart mobility context (smart + mobility + mining). Several studies matched the criteria of keyword search; however, none of them in reference to the process mining, but mostly focusing on data mining and data analysis using different algorithms. A relevant study by Anchal and Mittal (2019) surveyed the existing smart parking system by looking at how the received data from the parking sensors can be processed through filtering and data fusion. Also, they reviewed different data mining techniques that can help identify patterns in the IoT-enabled smart parking system. Aggarwal and Toshniwal (2018) studied the applicability and corresponding data mining techniques for smart mobility issues. With an objective to reduce the number of circulating vehicles, an example is provided by Lira (2019) who improves ride-matching algorithms with alternative destinations and identifies potential users for transportation services by exploring the content of posts on microblogging platforms. On a similar note, Zhong et al. (2016) compared urban mobility patterns in London, Singapore and Beijing using smart card data for the period of one-week focusing on understanding the regularities in patterns of transit use, but also found regularity in variability. Pronello et al. (2018) also analysed mobility patterns using smart card data mining, and in this way, improving the design of transport supply and mobility services to meet the user needs. As stated, no relevant studies have been found in reference to the process mining – this supporting the importance of the topic and its pioneer position in the smart city context.

Higher education

As event data are becoming more accessible and process mining techniques mature, an increasing number of researchers are looking into opportunities for a better understanding of educational processes. Educational Process Mining (EPM) is used in
a wide range of settings, some of which are presented here. Devi and Suryakala (2014) present valuable cases of process mining in the context of higher education systems such as discovering extreme values in student outcomes, predicting student performance, identifying potential dropouts, and students in need of assistance. On a similar note, Mukala et al. (2015) use process mining techniques to monitor and analyse student learning habits based on data collected from Massive Open Online Courses (MOOCs) establishing that successful students always watch videos in the recommended sequence, while the opposite is true for unsuccessful students. Related to MOOCs, Umer et al. (2017) propose a process mining approach to enhance the student learning experience by combining different machine learning techniques with process mining features to measure the effectiveness of different techniques. The ultimate aim of that particular data-based approach is to help improve the student learning experience and reduce dropout rates in MOOCs. Another study focused on the visualisation of students’ behaviour using process mining techniques to inspect student graduation probability by discovering, monitoring, and improving processes based on the event log and trace data (Douzali & Darabi, 2016). Van Der Aalst et al. (2015) even proposed that process cubes should be used as a way of organising event log data in a multidimensional data structure adapted for process mining to allow comparison of different process variants or different groups of cases.

**Setting the context of the two case studies**

**Smart mobility**

In the city of Split in Croatia, by installing parking sensors and introducing the Smart Parking App, the objective was to contribute to reducing congestion, lowering exhaust levels, and reducing stress levels among drivers by making it easier for drivers to find parking spaces. The sensors detect a vacant or occupied parking space, and the status of the parking spaces is available at http://smart.splitparking.hr. The overview is presented in the form of pins on the map containing information about the number of vacant spaces (Figure 2) with the possibility to navigate the user to the nearest available or selected parking space (Split parking, 2019). Considering that sensors continually detect whether a place is vacant (0) or occupied (1) a considerable amount of data is recorded; however, with only several characteristics suitable for process mining. Each record contains the following data: id, id_parking_space, occupied, date, and vendor_id. Attributes “id” and “vendor_id” are unique and generated each time a parking space changes the status from occupied to vacant and vice versa. Attribute “occupied” is therefore binary. “Date” is a timestamp (formatted for example “2019-12-18 12:47:19”) while “id_parking_space” represents a specific parking space in the city.

The issues of incomplete and raw data have been addressed already in the paper in referring to Van Der Aalst’s (2015) guidelines for logging. Even though in this particular case, the data is not recorded in line with the guidelines, the case can serve as a demonstration that event data containing several attributes can contribute to the more straightforward conceptualisation and building of simulation models. There is a noticeable lack of information related to tracking a specific “id” since all “ids” are unique. Furthermore, there is only one activity that is the same for all “ids” – parking, while data about the resources (parking spaces) is only available as a binary value. The aim of the simulation can be related to optimisation scenarios, determination of peak load, or for example to identify poorly used parking spaces and release these to the general public (for example, for long term leases or similar), and in that context, the potential of process mining as a basis for building a simulation model is tested.

Data processing was performed based on 114,931 unique records collected from a
randomly selected parking lot in the city of Split within one year – 2019. As a part of the Extract, Transform, and Load (ETL) process, the necessary amendments were made to enrich the dataset with additional information related to time dimension so that it would contain vacancy/occupancy per weekdays and hours of the day.

Figure 2
Smart Split Parking App Dashboard

Source: Split parking, 2019

Higher education
Learning Management Systems (LMS) can be used to support traditional courses (to a lesser extent, usually for online publication of learning material), in a hybrid-learning and fully-online learning settings. The latter approach should be supported by a good number of features offered by the system, and this is the reason why, for this case, data from a fully-online course was used. Data is generated and recorded in Moodle LMS, a system used from the academic year 2008/2009 onwards at the Faculty of Economics in Split. As a part of the first-year course “Information Technology”, students can access the e-course “Information Security” for eight weeks with the aim to raise their awareness of information security concepts and information security measures. Students can access course resources and activities (reading texts, watching videos, completing surveys, and more) in no particular order, in the sequence and dynamics that suit them best. To complete the course, they are required to achieve 70% of points in the test, without restrictions related to the maximum number of times to access the test or the delay between test attempts. For the study, data collected in the academic year 2018/19 is used from a Moodle report that records all the e-course activity data for all available resources. Selected data were exported to a file in .xls format suitable for further analysis in the process mining tool.

Analysing the case studies
Since the general aim was to evaluate the role of process mining results as inputs for discrete-event simulation modelling for both case study examples, here the simulation
model building blocks (entities, activities, control-flow, and resources) with regards to the potential of using process mining results are considered for each case.

Analysis of smart mobility case study

Entity. As mentioned above, in this particular case, id and vendor_id are unique and are generated each time a parking space is occupied or vacated; therefore, statistical processing of the entire set or a sample of data is possible. Monitoring an entity that can perform various activities in the system by occupying and releasing resources in this example is reduced to analysing a unique entity (car) for which data was not collected over time (longitudinally), and analysing only one activity (parking), as well as selecting a vacant parking space (resource). Given that arrivals are random, it is possible to select data where occupied = 0 and calculate an average time between the records that would correspond to the average time between arrivals of the car. For the time between the arrivals, it is possible to determine the mean of the exponential distribution. Actual entity arrival is a piece of critical information; however, in this example, data is collected for each entity arrival and departure, but under a unique id, i.e. arrival/departure sequence is not linked to the same entity. Concerning entities, it can be stated with certainty that only one entity will enter the system/parking space at a given time with each arrival. Descriptive statistics and statistical distributions for parking frequency per hour can be calculated using, for example, Input Analyzer tool by Rockwell Software: e.g. for a specific parking spot (labelled as 1062) Frequency = 10,519, Min = 1, Max = 23, Sample Mean = 12.1, Sample Std Dev = 6.92. Distribution is Beta, expression: 0.5 + 23 * BETA (0.888, 0.874), Square Error: 0.000982, Chi-Square Test (number of intervals = 23, degrees of freedom = 20, test statistic = 219, with corresponding p-value <0.005).

Activity. By looking at the parking activity whereby an entity occupies a parking space (1) for a certain period and then releases it without any particular expenditure of resources, it is possible to determine the duration of the activity, as well as certain specificities related to a particular parking space (resource). Figure 3 presents the frequency, relative frequency, median duration, and mean duration for the activity (parking) by hours of the day. It is interesting to compare the median and mean values of duration. Values of medians, ranging from 23 seconds to 4 minutes of occupancy and vacancy by hours of the day, indicate that 50% of data (frequency) less than or equal to this value, do not fall into the charged category (since the parking is free up to 5 minutes). Parking in the afternoon usually lasts longer than in the morning, taking into account the mean duration. Based on this data, it is possible to determine the type of distribution for the delay.

Control-Flow. Control-flow definition and gateway routing logic in this particular case is not satisfactorily supported. Although analyzing 15 parking spaces in this particular case, process map (Figure 4) shows the arrival of unique (anonymous) cars and the occupancy of 3 available parking spaces (labelled as 1053, 1062, and 1056). For example, parking space marked as 1062 has been occupied in 11,024 occasions by cars during the whole year, in contrast to 10,712 occasions when it was free. Considering that in this case, there is no sequential relationship between activities, analysing traces in the log process map does not contribute to the process of building a simulation model. However, by analysing the frequency information displayed on the map, it is possible to determine the routing logic, i.e. the probability of occupying a specific parking space (per day of the week or hour of day).
Resources. In this case, there are 15 parking spaces representing resources that can perform the same activity (provide a timed parking service), with entities (cars) that seize-delay-release the resources. Specifically, resources are first allocated, followed by a process-delay, and then the allocated resource is released, which in this example does not affect resource expenditure but the generation of revenue. Collected data indicate that there are specific differences between the 15 available resources (Figure 5), which may serve to support the resource optimisation procedures. Namely, in the situation of resources underuse, or overcapacity even at peak loading times, there is potential for planning the termination of certain resources. In this case, it would lead to more efficient use of the public property, if for example, the management was to introduce green islands in these spaces.
Analysis of higher education case study

Entity. Process mining can be useful for analysing data about a series of different types of activities such as browsing, deleting, modifying, adding content within an e-course. These activities are generated in the learning process by the frequent involvement of students throughout the semester and their interaction with the learning material. In this second case, the process begins with student enrolment in the course and continues with several different activities denoting students’ progress in the e-course. All the activities performed by the entity “student” are automatically recorded to the
system, so it is possible to monitor their progress while attending the e-course. The time component is recorded as accurate entity arrival in the format "22/03/18, 13:28" and is one of the critical factors in measuring process performance. Descriptive statistics and distribution for the frequency of access to the e-course and the use of specific resources within the e-course are analysed using the Input Analyzer tool by Rockwell Software, and a part of it is presented in Table 3. It is noteworthy that the distribution given here, considering it is based on a smaller data segment and that there are large variations in the observed data, can only serve to indicate the potential for the use of this particular data in simulation modelling.

**Table 3**
Input Data Analysis of the LMS e-Course Access Data

<table>
<thead>
<tr>
<th>Resource</th>
<th>Count</th>
<th>Min</th>
<th>Max</th>
<th>Mean</th>
<th>Std</th>
<th>Distribution</th>
<th>Expression</th>
</tr>
</thead>
<tbody>
<tr>
<td>Choice</td>
<td>230</td>
<td>1</td>
<td>15</td>
<td>6.52</td>
<td>2.51</td>
<td>Normal</td>
<td>NORM(6.52, 2.51)</td>
</tr>
<tr>
<td>File</td>
<td>222</td>
<td>1</td>
<td>11</td>
<td>3.64</td>
<td>1.61</td>
<td>Gamma</td>
<td>0.5 + GAMM(0.745, 4.21)</td>
</tr>
</tbody>
</table>

Source: Moodle Event Log

**Activity.** The entity “student” performs educational activities (reading, writing) by interacting with certain resources in the e-course for a fixed time and then releasing them and moving on to the next activity or leaving the e-course. By using process mining tools, it is possible to determine the duration of the activities. Process discovery builds process models drawing from the data recorded in the event log. An event log can be used as an input to numerous process mining algorithms to visualise and uncover the actual behaviour (sequential steps) of students. Disco provides a complete set of process metrics for activities and paths absolute frequency: case frequency, the maximum number of repetitions, total duration, mean duration, maximum duration. The models illustrated here show the activities and their performance in the form of the absolute frequency of individual activities and the transitions between them. The resulting events over time (Figure 6) can also be tracked and used for validation of a simulation model. The tool calculates the total number of events (33,149), number of specific cases (366), number of specific activities (73), median case duration (42.2 hours) and mean case duration (12.8 days).

**Figure 6**
Visualisation of the events generated by the students throughout the semester

Source: Overview diagram “Events Over Time” created in Disco process mining tool

**Control-Flow.** Control-flow definition and gateway routing logic are well-supported in this case. The process map illustrates students accessing the e-course, performing
different activities using different resources, and leaving the e-course upon completion. The Disco tool allows fine-tuning of the percentage of displayed activities and paths. Process map that represents 100% of activities and 56.7% of paths is not informational due to its complexity, and it does not serve as a useful input for the simulation modelling process itself. However, reducing the activity view to, for example, 17.6% and the path to 10.2% (Figure 7), provides a perspective that can support control-flow and routing logic modelling. In this particular case, there are several sequential relationships between activities; therefore, the analysis of the traces in the log files and the process map can contribute to the process of building a conceptual and computer simulation model. Also, by analysing the frequency information displayed on the map, it is possible to determine the routing logic, that is, the probability of an occurrence of a specific activity and the routing of entities in selecting a subsequent activity.

**Figure 7**
Process Map (set to 17.6% Activities and 10.2% Paths)

![Process Map](image)

Source: Process map created in Disco process mining tool

**Resources.** In this scenario, the frequencies and relative frequencies for the resources are: System (f = 16,535; 49.88%), Test (f = 9,307, 28.08%), Page (f = 3,871, 11.68%), Choice (f = 2,073, 6.25%), File (f = 807, 2.43%), Dictionary (f = 521, 1.57%), and so on, as is presented in Figure 8. Statistics are also automatically calculated for the use of all resources (11), such as minimum frequency (1), median frequency (521), mean frequency (3,013.55), maximum frequency (16,535), and frequency standard deviation (5,294.67).
Discussion

The paper supports the findings that there are still significant research and practical challenges in collecting event data for process mining, and consequently, in integrating the two fields—process mining and discrete-event simulation. The potential for the use of process mining in building a simulation model was elaborated and reviewed based on a related study by Martin et al. (2015) per each of the aggregated simulation building blocks: entities, activities, control-flow, and resources. The concept brought forth in Table 2 was then developed further and empirically tested, and the results were broken down per simulation building block in two noticeably different case studies. It was made apparent that the success of process mining depends on the availability of event logs that are clearly defined and need to refer to a case (i.e. process instance) and an activity (i.e. step in the process), this way answering RQ2. Not all (or better even: not a lot of) information systems can simply generate event logs that match presented 15 guidelines and recommendations, while most generate raw data that needs to be linked to cases and activities when creating or using process models (Van Der Aalst, 2015).

The two case studies confirmed this particular situation. Process mining results based on the parking data represent a poor-data case, while the process mining on LMS data can be considered a rich-data case. As investigated within RQ1, the results of PM analysis point to the conclusion that the quality of event datasets affects PM results. In the first case, with limited data, the findings support the conclusions noted by the IEEE Task Force on Process Mining (2011), where event data incompleteness has been noted as one of the important challenges within “Finding, Merging, and Cleaning Event Data” challenge in The Process Mining Manifesto. R’bighui and Cho (2017) investigated whether the defined challenges have been resolved in the following years, and found that this area is still interesting to the research community, however, due to a variety of different sources of event data, there is still a need for additional research. For example, in the pursuit to rediscover the process models from small incomplete event logs, Leemans et al. (2014) successfully introduced a new algorithm based on the inductive miner and probabilistic behavioural relations, that are less sensitive to incomplete logs. As the quality of process mining results directly depends on event logs, finding, merging and cleaning event logs were reported as the first challenge in PM manifesto understandably so.

On the contrary, rich-data cases offer more possibilities and promise in terms of delivering more conclusive and relevant PM results. As such they represent higher-
quality input for simulation modelling, as evidenced in studies, for example, by Phan et al. (2019), Tamburis (2019), Jadrić (2019), Abohamad et al. (2017), Zhou et al. (2014), and Rozinat et al. (2009), where valuable information has been collected, i.e. potential for improvements in the processes were identified. In the study by Nakatumba et al. (2012), it has been confirmed that combining process mining with simulation leads to better understanding, modelling, and improving real-life business processes.

Apart from the contribution in the area of simulation modelling (by providing a framework for more objective building of simulation models), this paper provides contributions in two other domains considering the two case studies:

Smart City (SC) domain is characterised as an area of open and user-driven innovation (Schaffers et al., 2011) thus being a good platform for experimentation and implementation of new technologies, products, and services. Smart mobility as one of the SC pillars aims to increase the efficiency of urban transportation (Giffinger & Gudrun, 2010) and to reduce traffic congestion and harmful environmental influences, in this way positively influencing the quality of citizens’ lives. The practical implications of designing a simulation study based on the results of process mining in the parking domain are numerous. For example, business value can be found in the analysis of what-if scenarios of using a mobile application such as the one presented in the paper, e.g. by introducing pay-per-use and not per fixed (pre-paid) period, or by deliberating code-sharing in case a user has not used up all the pre-paid time promoting in that way concepts of the smart and sharing economy. In this specific case of smart parking, the service is handled by two companies, the first one being a city-owned company that is also the owner of the infrastructural assets (including sensors), and the other one handling ticketing-payment process (outsourced activity). Information on ticketing-payment was not available to the authors, and therefore cross-organizational mining has not been performed, with a view to do so in the future.

Educational Process Mining (EPM) is a relatively new research area within Educational Data Mining (EDM) that aims to uncover valuable patterns by using logs collected from educational settings to analyse and provide a visual representation of educational processes and to provide better insights (Bogarín et al., 2018). Results-based process mining of educational data, such as the one presented in this case, followed the general concept of process mining by providing the basis for discovering, monitoring, and improving real processes by extracting new knowledge from logs that are automatically recorded by frequently used information systems. The practical implications of conceptualising a simulation study based on the results of a process mining case in an educational environment are numerous. Based on the process-related knowledge discovery from extensive records of educational events in the form of new process models that track key performance indicators, it is possible to: analyse the “real” educational processes and their alignment with the curricula; improve the performance indicators of educational processes such as execution time, bottlenecks, decision points, and similar; personalise educational processes by recommending the most suitable learning units or learning paths to students (all depending on their profiles, their preferences or target skills) (Grigorova et al., 2017). In addition to this, by building and using a simulation model based on LMS data, the testing of different what-if scenarios is possible without interfering with the actual educational process.

Conceptual models, being an important part of business process simulations, are usually based on information sources such as process documentation, expert interviews, and observations. There are many issues with these traditional sources, as they differ in formats and often include the problem of biases, which may lead to the
discrepancy between the simulated model and the reality (Rozinat et al., 2009). As the behaviour of business processes is increasingly registered in the event logs of most of the information systems today (customer relationship management systems, enterprise resource planning systems, and other), there are growing opportunities to introduce event log knowledge, extracted from log files using process mining techniques, as an additional input to building simulation models. The rationale behind the new research on the links between process mining and simulation modelling is clear: event logs are files where process-aware information systems are registering the information about the actual behaviour of the process (as successfully illustrated by Martin et al., 2014). In order to extract useful knowledge from an event log, process mining techniques have to be employed. The results, in the form of new knowledge and insights, can then be validated through traditional information sources, but also by staff members and experts as they may locate errors and inaccuracies in data sets, which are the basis for process mining (Abohamad et al., 2017).

Conclusion
This paper provided an overview of the possible scenarios in which process mining concepts could be used to support simulation model construction. The link has been demonstrated per each of the aggregated simulation building blocks: entities, activities, control-flow, and resources. The whole process is presented in the paper for two different models. The results related to activities, control-flow and resources for the simulation entities “car” and “student”, together with the timestamps, descriptive statistics, and distributions can be used in the specific phases (most of all in the input phase) of the conceptual and discrete-event simulation model development, as well as in the validation procedures.

In addition to this, the paper emphasised the importance of complete event log data, then suitable for process mining in different domains. Process maps and statistical calculations in the cases of smart parking and LMS data were presented using the Disco tool, and along with the implications of the results for each of the building blocks.

In addressing one of the key challenges that motivated the research – combining process mining with simulation (RQ2), this study addressed other challenges noted in the PM manifesto (IEEE Task Force, 2011; Van Der Aalst et al. 2012) as well: from the category of finding, merging and cleaning event data – incomplete event data (RQ1). Building on the existing studies (mostly to support the framework for mapping process mining with simulation provided here, e.g. Martin et al. (2015) and Abohamad et al. (2017), this study contributed both to process mining and discrete-event simulation research.

In the smart city context, smart mobility, in particular, presents an important area with the potential for the use of discrete-event simulation (Jadrić et al., 2019). Coupled with process mining the research area offers a suitable innovation environment. Practical implications in the smart parking case refer to possible improvements in business processes by implementing better use of (public) resources, but also point to the constraints of information system in use, in terms of the non-existence of specific event data. In the case of higher education, PM use on LMS data can contribute to a better prediction of student behaviour, new modalities of work balanced with students’ needs and preferences. The smart context is highlighted in this domain as well; according to Waheed et al. (2018), there is a need to integrate learning analytics research with multidisciplinary smart education and smart library service in the future.

Limitations of the study include sub-optimal data used in the two case studies, and further research is required to offer and substantiate improvements in future strategies.
and action plans. In addition, cross-organizational process mining techniques have not been addressed in the case of smart parking data to get the complete visualisation of the process, which would certainly be the aim of the future case study. To summarize, future research on combining process mining and simulation needs to be extended further to provide a stronger theoretical and empirical background of PM, which will then be efficient in constructing the structure of the simulation model, equal to real-life.

References


About the authors
Mario Jadrić, PhD is an Associate Professor at the Faculty of Economics, Business, and Tourism (FEBT), University of Split, Department of Business Informatics. He holds a PhD from the University of Zagreb, Faculty of Organization and Informatics. (Co)-author of more than 60 scientific papers on the topic of e-learning, technological innovations, business processes improvement and user perception of new technologies. He teaches e-learning in Business Environments, Business Process Simulation and Business Information Systems at undergraduate and graduate level and Computer Simulation at the PhD level. He is a member of the research team of MIS4SC project financed by Croatian Science Foundation and has participated in several international and national projects. The author can be contacted at jadric@efst.hr

Ivana Ninčević Pašalić is a Research and Teaching Assistant at FEBT's Department of Business Informatics, and a PhD candidate at the University of Split. She teaches lab classes for the courses Multidimensional Information Systems and Management of IT projects. Her previous working positions include being Internal Auditor for a US-based international organization and Operations Manager at a Croatian private company. She is also a member of the research team of MIS4SC project. Within the framework of the project, her research is focused on G2C and C2G interactions in smart cities, with a special focus on citizen engagement via different information and communication technologies. The author can be contacted at nincevic@efst.hr

Maja Ćukušić, PhD is an Associate Professor at FEBT, University of Split, Department of Business Informatics. Before joining academia, she worked for three years in a Dutch company in the design and implementation of complex ICT solutions for global markets. Currently, she is the manager and the principal investigator of the project financed by the Croatian Science Foundation on the topic of smart cities, leading the group of three PhD students and five international researchers. She is also a key expert for e-learning in the SEA-EU European University Alliance. In her teaching activities (courses OLAP systems, ERP systems, E-business, E-learning), she uses examples and studies on the use of business intelligence technologies, visualization tools (open data), smart devices and similar. The author can be contacted at mcukusic@efst.hr
Portfolio Optimization Efficiency Test Considering Data Snooping Bias

Aleš Kresta
VSB – Technical University of Ostrava, Faculty of Economics, Czech Republic
Anlan Wang
VSB – Technical University of Ostrava, Faculty of Economics, Czech Republic

Abstract

Background: In the portfolio optimization area, most of the research is focused on in-sample portfolio optimization. One may ask a rational question of what the efficiency of the portfolio optimization strategy is and how to measure it. Objectives: The objective of the paper is to propose the approach to measuring the efficiency of the portfolio strategy based on the hypothesis inference methodology and considering a possible data snooping bias. The proposed approach is demonstrated on the Markowitz minimum variance model and the fuzzy probabilities minimum variance model. Methods/Approach: The proposed approach is based on a statistical test. The null hypothesis is that the analysed portfolio optimization strategy creates a portfolio randomly, while the alternative hypothesis is that an optimized portfolio is created in such a way that the risk of the portfolio is lowered. Results: It is found out that the analysed strategies indeed lower the risk of the portfolio during the market’s decline in the global financial crisis and in 94% of the time in the 2009-2019 period. Conclusions: The analysed strategies lower the risk of the portfolio in the out-of-sample period.

Keywords: data snooping bias, financial crisis, hypothesis test, minimum-risk portfolio, portfolio optimization

JEL main category: G11
JEL classification: G11, G17
Paper type: Research article

Received: Jan 31, 2020
Accepted: Jul 06, 2020

Acknowledgments: The authors were supported through the Czech Science Foundation (GACR) under the project no. 18-13951S and the SGS research project of VSB-TU Ostrava under the project no. SP2020/11. The support is greatly appreciated.

DOI: 10.2478/bsrj-2020-0016
Introduction

Since the pioneering work of Markowitz (1952) that put out the foundations of modern portfolio theory, it is still a lively and open area with a lot of attention from both academics and practitioners. While academics generally focus more on the question of different models of portfolio selection, paying attention mostly to the theories and assumptions, practitioners focus also on the verification of particular strategies. The question they ask is what the efficiency of the portfolio optimization strategy is.

The standard procedure is that the parameters of the model are estimated from the time series of returns in a historical period, which is usually called the in-sample period. The portfolio performance is then observed and measured in the period following the in-sample period. This observed period is usually called the out-of-sample period and the portfolio performance is generally lower in the out-of-sample period than in the in-sample period. In order to confirm the suitability of the proposed strategy, the out-of-sample performance is usually compared to the chosen benchmark. If the proposed strategy delivers better out-of-sample results than the benchmark, it is considered suitable.

Although the application of the benchmark is commonly accepted, its informative value is rather poor – it answers the question of whether and how much the tested strategy overperformed the benchmark in one particular period. However, it does not say whether the overperformance is high enough to be considered as significant or whether it is just due to the randomness in data and luck. Also, another drawback of this simple approach is that it does not address the data snooping bias – if more strategies are analyzed, then it is more probable that the best strategy overperforming the benchmark is found.

In this paper, we address this gap by proposing a rather different approach to verify the efficiency of the portfolio strategies. The approach is based on the hypothesis inference methodology. Put it simply, the principle is to generate many random portfolios and compare the out-of-sample performance of the analyzed strategy with performances of these random portfolios. Data snooping bias is also considered in the proposed approach. Moreover, in the empirical part of the paper, we investigate whether the classical minimum variance model (Markowitz, 1952) and fuzzy probabilities minimum variance model (Tanaka et al., 2000) decrease the risk in the out-of-sample period.

The paper is divided as follows. The following section provides a brief literature review of applied benchmarks. Then, in the following section, the analyzed portfolio strategies are introduced and the method of testing the efficiency of portfolio strategies is presented. Empirical results are provided in the following section. First, the focus is given to the global financial crisis period. Then, the results on the rolling window basis in the period 2006-2019 are presented. The last sections provide a brief discussion of the results and conclusion to the paper.

Literature review

Various benchmarks can be found in scientific literature; however, there are few groups of benchmarks, which are generally applied. The first benchmark is 1/N strategy, which is also called a naive diversification strategy. The 1/N strategy is easy to implement because it is not necessary to estimate the future returns of the assets, the assets of the naive portfolio are invested with equal weights. DeMiguel et al. (2009) analyzed the differences in the performance of several optimization methods with that of the 1/N strategy, and they found that the effect of estimation error on return
probability distribution is large in those optimization models and this type of error can be avoided by using the 1/N weights.

The second benchmark is the classical Mean-Variance model or Mean-VaR model. Since more real-life conditions have been considered, for example, the investors’ subjective preference, the transaction costs, the liquidity of the portfolio and so on, the classical Mean-Variance model is improved by incorporating various additional constraints, so the classical model becomes a widely used benchmark to compare with those enhanced approaches, see e.g. Fulga (2016), Ranković et al. (2016), Lwin et al. (2017), or Babazadeh and Esfahanipour (2019).

It is also common to apply market indices as a benchmark to compare the performance of proposed methods. Solares et al. (2019) pointed out the main problem of applying market indices as the benchmark: the performance of portfolios is often compared to that of popular indices, but it is hard to reach the performance of the indices because there is a difference between characteristics of the stocks in the portfolios and the stocks contained in the index. So, to avoid this trap, it is recommended to construct the portfolio with only the stocks, which are selected from the components of the benchmark index.

Besides considering one particular portfolio optimization approach as a benchmark, it is also necessary to apply a benchmark dataset when developing a new approach in the portfolio optimization problem. Most of the studies are based on either case studies or publicly available benchmarking datasets, see Kalayci et al. (2019). In the empirical analysis of this paper, the dataset of Dow Jones Industrial Average (DJIA) index is applied; it is a small dataset of 30 stocks while it is persuasive enough to explain the investment environment in the optimization problem. What’s more, the advantage of the small dataset is also its relatively smaller computational complexity. In the future, the small dataset of DJIA could be used as a benchmark dataset to compare with large-scale datasets, which can verify the applicability of the proposed models in complex environments and global markets.

Methodology

Applied Portfolio Models

Portfolio models applied in the paper follow the classical mean-variance framework, i.e. only expected return (mean), its variance, and their inter-relationship are considered. Let us denote $x_i$ as the weight of $i$th asset in the portfolio. Short sales are excluded from the models, so the values of $x_i$ satisfies $0 \leq x_i \leq 1$ for all assets. If the expected return of $i$th asset is denoted as $E(R_i)$, then the expected return of a portfolio $E(R_p)$ is the weighted average of $E(R_i)$:

$$E(R_p) = \sum_{i=1}^{N} x_i \cdot E(R_i) = x^T \cdot E(R), \quad (1)$$

where $N$ is the total number of assets in the portfolio, $x = [x_1, x_2, ..., x_N]^T$ is portfolio composition and $E(R) = [E(R_1), E(R_2), ..., E(R_N)]^T$ is the vector of expected returns. The variance and standard deviation of the portfolio return are calculated by means of covariances $\sigma_{i,j}$ of the asset returns for all asset pairs $(i,j)$,

$$\sigma_p^2 = \sum_{i=1}^{N} \sum_{j=1}^{N} x_i \cdot \sigma_{i,j} \cdot x_j = x^T \cdot Q \cdot x, \quad (2)$$

$$\sigma_p = \sqrt{\sigma_p^2}, \quad (3)$$

where $Q$ denotes covariance matrix, $Q = [\sigma_{i,j}, i = 1, 2, ..., N, j = 1, 2, ..., N]$. The minimum-variance portfolio can be found by solving the following quadratic optimization problem,

$$\text{minimize } \sigma_p^2 \quad (4)$$
subject to
\[ \sum_{i=1}^{N} x_i = 1 \quad (5) \]
\[ x_i \geq 0, i = 1, \ldots, N \quad (6) \]

The question is how to estimate the parameters of the return probability distributions. In the simplest approach, let us call it historical estimation, the characteristics of the observed sample distribution are calculated. Specifically, the expected returns are estimated as means of observed historical returns,

\[ E(r_i) = \bar{r}_i = \frac{1}{m} \sum_{i=1}^{m} r_{i,m}. \quad (7) \]

The covariance matrix is estimated in the same way,

\[ Q = \hat{Q} = \left[ \hat{\sigma}_{ij} \right] \quad (8) \]
\[ \hat{\sigma}_{ij} = \frac{1}{m} \sum_{k=1}^{m} (r_{i,k} - \bar{r}_i)(r_{j,k} - \bar{r}_j). \quad (9) \]

The problem of historical estimation is the excessive sensitivity of the portfolio composition to errors in parameter estimates (due to the length of time series, the number of assets, etc.). The illustrative example can be found in DeMiguel et al. (2009).

In the Bayesian approach, the estimation of the parameters of return probability distributions, i.e. the vector of expected returns \( E(R) \) and the covariance matrix \( Q \), considers the subjective (a priori) assumption of the shape of this distribution. The resulting (a posteriori) probability distribution is then a combination of the a priori assumption and the probability distribution of the observed sample. Although there are different possibilities for applying this approach, the methodology commonly referred to as the Bayes-Stein portfolio (BS) is applied in the paper. The foundations of this approach have already been laid by Stein (1956) and James and Stein (1961). The estimation suggested in Jordon (1986) is applied:

\[ E(r_i^{BS}) = (1 - \xi) \cdot \bar{r}_i + \xi \cdot \bar{r}, \quad (10) \]
\[ \xi = \frac{(N+2)+m:(\bar{r}_i-r)^T Q^{-1} (\bar{r}_i-r)}{N+2+m:(\bar{r}_i-r)^T (\bar{r}_i-r) + 1}, \quad (11) \]
\[ Q^{BS} = \hat{Q} \left( 1 + \frac{1}{m+\xi} \right) + \frac{\xi}{m+\xi} \frac{1}{1+\xi} \hat{Q} \times 1_N, \quad (12) \]
\[ \zeta = \frac{m \bar{\xi}}{1-\xi}, \quad (13) \]

where \( \bar{r}_i \) is the historical estimate of the expected return of the \( i \)th asset, see (7), \( \bar{r} \) is the a priori expected return on the assets, \( N \) is the number of assets and \( m \) is the number of historical observations of returns (sample size), \( \hat{Q} \) is the historically estimated covariance matrix, see (8). Jorion (1986) proposes to determine \( \bar{r} \) as the return of the minimum-variance portfolio. However, we rather consider the average expected return, which saves one optimization in the procedure. As can be seen, the shrinkage factor \( \xi \) depends on the number of assets \( N \) (with an increasing number of assets the estimation error increases), the number of historical observations \( m \) (the shorter the history, the higher the estimation error) and on the dispersion of estimated expected returns from a priori assumption (the greater the dispersion, the greater the estimation error).

Another approach of how to handle uncertainty in probability distribution parameters is to apply the fuzzy theory. Tanaka et al. (2000) proposed two types of portfolio optimization models. The first model is based on fuzzy probabilities and aims to minimize the variance of the portfolio return while the latter utilizes possibility distributions and minimize the spread of the portfolio return. The first model is applied in the paper. The model considers not only historical returns \( \{r_i, i = 1, \ldots, N\} \), but also possibility grades \( \{h_i, i = 1, \ldots, N\} \), which represent a similarity between the future state of the stock market and the state of \( i \)th sample offered by experts.

Given the historical returns and possibility grades, the fuzzy weighted expected return can be calculated as follows,
$$E(r^F_i) = \frac{\sum_{j=1}^{m} h_j r_{ij}}{\sum_{j=1}^{m} h_j},$$

(14)

and fuzzy weighted covariance matrix $Q^F = [\sigma^F_{ij}, i = 1, ..., N, j = 1, ..., N]$ can be defined as:

$$\sigma^F_{ij} = \frac{\sum_{k=1}^{m} (r_{ik} - E(r^F_i))(r_{jk} - E(r^F_j))h_k}{\sum_{k=1}^{m} h_k}.$$

(15)

These estimates can be directly applied in the portfolio optimization model (4)-(6).

**Portfolio efficiency test**

The rational question one can ask is what the efficiency of the portfolio optimization strategy is. Let's consider the portfolio strategy with observed out-of-sample performance $p$. The observed out-of-sample performance is, in fact, a realization of random variable $P$. Let us consider the following null hypothesis: the performance of the portfolio strategy is the same as of random strategy. The alternative hypothesis is that the performance of the portfolio strategy is better than of random strategy. The distribution of random variable $P$ under the null hypothesis can be obtained by generating random portfolio compositions and calculating their performances in the out-of-sample period. Then, the classical statistical inference approach is to calculate one-sided $p$-value:

$$p^s = \Pr(P > p),$$

(16)

in case that the performance measure should be maximized (Sharpe ratio, etc.) and

$$p^s = \Pr(P < p),$$

(17)

in case that the performance measure should be minimized (maximum drawdown, variance, etc.). If $p^s$ is smaller than the chosen significance level (0.05 or 0.01), the conclusion can be made that analyzed strategy performs better than random in the out-of-sample, i.e. the null hypothesis should be rejected and the alternative hypothesis should be accepted.

The one-sided version of the test is applied because the aim is to prove that the performance of the analyzed strategy is better than random. Alternatively, a two-sided version of the test can be applied, i.e. alternative hypothesis would take the form that the performance of the portfolio strategy is not the same as of random portfolio. However, in this case, rejecting the null hypothesis would only mean that the performance of the portfolio strategy is non-random, not knowing whether it is better or worse than random.

However, there is one more issue that must be taken into account – data snooping bias also named as data mining bias or backtest overfitting, see e.g. White (2000) or Bailey et al. (2014, 2017). This bias occurs when more than one strategy is analyzed, which is typically the case. Let us consider $k$ portfolio strategies, e.g. three above mentioned approaches to parameters estimation. The out-of-sample performances \{\pi, i = 1, ..., k\} are known for these strategies. Of course, only the strategy with the best out-of-sample performance measure $p = \max\{\pi, i = 1, ..., k\}$ is usually considered further. However, applying the simple test (16)-(17) would be a mistake as the distribution of a random variable (now the random variable is the performance of the best out of $k$ strategies) differs from $P$. We denote this new random variable as $P_k$, where $k$ is the number of strategies originally analyzed. Note that simple random variable $P$ is a special case of $P_k$ for $k = 1$. Then, the bias-free statistical test should be,

$$p^s = \Pr(P_k > \max\{\pi, i = 1, ..., k\})$$

(18)

for maximization performance measures and

$$p^s = \Pr(P_k < \max\{\pi, i = 1, ..., k\})$$

(19)

for minimization performance measures.
The only problem left is the construction of the statistics $P_k$. In order to do so, its meaning must be kept in mind – it is the best performance out of $k$-tuples of random portfolios. Thus, a large number of $k$-tuples of random weights are generated.

The procedure of test statistics calculation is as follows. First, $k$-tuples of random numbers $y \in [0,1]^{N-1}$ from standard uniform distribution are generated and sorted so that $0 \leq y_1 \leq \cdots \leq y_{N-1}$. Then, the simulated weights $x$ of the random portfolios are calculated as

$$x = (y_1, y_2 - y_1, y_3 - y_2, \ldots, y_{N-1} - y_{N-2}, 1 - y_{N-1}).$$ \hspace{1cm} (20)

This approach guarantees that the sum of weights is equal to one. For each portfolio composition from given $k$-tuples the out-of-sample performance is calculated and only the best performance is recorded, i.e. the maximum for maximizing performance measures and minimum for minimizing performance measures. The probability distribution of the statistics is obtained by repeating this procedure many times (in empirical analysis 50,000 times).

The last issue, which should be addressed, is the choice of performance measure. The strategies can be evaluated in many ways. The following examples are mentioned:

- The annual return corresponds to the out-of-sample return recalculated to annual basis. Investors want to maximize this measure.
- The volatility of (daily) returns – the more volatile the returns are, the riskier the investment is. Different measures for the volatility can be applied; the examples are standard deviation (SD), mean absolute deviation (MAD), Value at Risk (VaR), Conditional Value at Risk (CVaR), etc.
- Investors usually analyze also maximum drawdown – the maximum relative decline in the portfolio value over the analyzed period, see e.g. Chekhlov et al. (2005) or Magdon-Ismail et al. (2004).
- There is also the variety of performance ratios, which are simply the ratios of the reward and risk. The well-known performance ratios are Sharpe ratio (Sharpe, 1966, 1994), Gini ratio (Shalit and Yitzhaki, 1984), mean absolute deviation ratio (Konno and Yamazaki, 1991), mini-max ratio (Young, 1998), Rachev ratio (Biglova et al., 2004) and others. For the summary, see Farinelli et al. (2008).

In our paper, the focus is on the portfolio strategies minimizing the risk. Thus, only the performance measures quantifying the riskiness of the portfolio are applied.

**Results**

**Global Financial Crisis**

In this section, we study one specific period, which covers the market’s decline phase during the global financial crisis (GFC) to see how efficiently the portfolio strategies worked during the decline of the markets. In order to do so, the period prior to GFC, concretely March 7, 2006 – August 31, 2007, is reserved as the in-sample period. The period with the market’s decline phase is the out-of-sample period (September 1, 2007 – March 2, 2009). The dataset obtained from finance.yahoo.com consists of daily closing prices of the components of Dow Jones Industrial Average index (DJIA). These prices are adjusted for paid dividends and splits. There are 29 stocks included in our analysis and the missing one is the stock of Visa Inc. due to the incomplete data in the chosen period. The dataset covers 3 years, and is evenly split into the in-sample period and the out-of-sample period. In Figure 1, it can be seen that in the in-sample period the DJIA shows an increasing trend, however, in the out-of-sample period, it keeps decreasing due to the 2007-2008 financial crisis. The minimum risk portfolios are
calculated from the in-sample data. Then, the verification of the obtained portfolios is performed with the out-of-sample data.

**Figure 1**
Historical Values of DJIA Index in In-sample and Out-of-sample Periods

![Figure 1](http://finance.yahoo.com)

Source: http://finance.yahoo.com

Four methods of portfolio strategy creation are analyzed: two models each estimated from daily and weekly returns. The models are Markowitz minimum variance model with classical historical estimation (MA) and fuzzy probabilities minimum variance model (FU). The Bayesian approach is not utilized, because for minimum variance portfolio it suggests the same weights as in case of classical historical estimation. The weights of the portfolios are depicted in Figure 2.

**Figure 2**
Compositions of minimum variance model (MA) and fuzzy probabilities minimum variance (FU) model estimated from daily and weekly returns

![Figure 2](image)

Source: own calculation

As can be seen from Figure 2, which depicts only non-zero weights, the classical historical estimation suggests a more diversified portfolio in terms of the number of assets; however, more than 50% of the portfolio is made up by two stocks (The Coca-
Cola Company and Johnson & Johnson). The portfolio of fuzzy probabilities minimum variance model is more evenly diversified, although with fewer assets.

For these four portfolios, the performance measures are calculated in the out-of-sample period. Only risk measures are considered. Specifically, the chosen risk measures are maximum drawdown (MDD), which is a commonly applied measure among practitioners, standard deviation of daily returns (SD), which is minimized in-sample, and mean absolute deviation of daily returns (MAD) as an alternative measure to the standard deviation. The values of the measures for analyzed portfolios together with two commonly applied benchmarks are depicted in Table 1.

Table 1
Out-of-Sample Performance Measures with Corresponding P-values

<table>
<thead>
<tr>
<th>Model</th>
<th>MDD</th>
<th>SD</th>
<th>MAD</th>
</tr>
</thead>
<tbody>
<tr>
<td>MA – daily data</td>
<td>35.67%</td>
<td>1.65%</td>
<td>1.05%</td>
</tr>
<tr>
<td></td>
<td>(.001)</td>
<td>(&lt;.0001)</td>
<td>(&lt;.0001)</td>
</tr>
<tr>
<td>MA – weekly data</td>
<td>36.57%</td>
<td>1.64%</td>
<td>1.05%</td>
</tr>
<tr>
<td></td>
<td>(.019)</td>
<td>(&lt;.0001)</td>
<td>(&lt;.0001)</td>
</tr>
<tr>
<td>FU – daily data</td>
<td>37.58%</td>
<td>1.75%</td>
<td>1.12%</td>
</tr>
<tr>
<td></td>
<td>(.040)</td>
<td>(&lt;.0001)</td>
<td>(&lt;.0001)</td>
</tr>
<tr>
<td>FU – weekly data</td>
<td>37.95%</td>
<td>1.75%</td>
<td>1.13%</td>
</tr>
<tr>
<td></td>
<td>(.051)</td>
<td>(&lt;.0001)</td>
<td>(&lt;.0001)</td>
</tr>
<tr>
<td>DJIA index</td>
<td>52.25%</td>
<td>2.14%</td>
<td>1.46%</td>
</tr>
<tr>
<td>1/N strategy</td>
<td>45.24%</td>
<td>2.23%</td>
<td>1.50%</td>
</tr>
</tbody>
</table>

Source: own calculation

As can be seen, for all three considered measures, the portfolios perform better than the benchmarks, thus, according to the classical rule of thumb, the conclusion is that these strategies work. However, is the claim that these strategies lower the risk in the out-of-sample period correct from the statistical point of view? To find this out, the distribution of the test statistics must be calculated. In order to do so, 50,000 times 4 (1 respectively) random portfolio compositions are simulated according to (20), for each portfolio the out-of-sample MDD, SD and MAD are calculated, and finally, for every foursome (respectively for each) portfolios the minimums of these risk measures are recorded. In this way, the distributions of the statistics are numerically obtained, see Figure 3. In the figure, the left column corresponds to the simple statistics (17) and the right column depicts the bias-free statistics (19) for four portfolio strategies. The range on the x-axes is the same to make the comparisons easier. Moreover, the fitted Gaussian distributions are added into the graphs.

It can be noticed that the bias-free statistics are shifted to the left, which means that for the same observed out-of-sample performance the higher p-value is obtained – there are more randomly generated portfolios with better performances. Moreover, it can be noticed that MDD statistics can be approximated by Gaussian distribution in the case of the simple test. In the case of the bias-free test, the statistics is negatively skewed with a heavier left tail. On the other hand, for SD and MAD the bias-free statics are almost normally distributed, but simple statistics are positively skewed with a heavier right tail.

When the mean and standard deviation are known, the classical t-test can be applied. Nevertheless, the p-values for all three bias-free statistics are calculated as the number of random-weights portfolios, which are better than analyzed strategy, divided by 50,000. The calculated p-values are depicted in Table 1. From the results, the following conclusions can be made. Firstly, the portfolio strategies do not create the portfolios randomly (i.e. the null hypothesis is rejected). These strategies lower SD and MAD in the out-of-sample period. Secondly, it can be concluded that the strategy minimizing the variance with standard historical estimation lower the maximum drawdown in the out-of-sample period (p-value for daily and weekly returns
is lower than 0.01 and 0.05 respectively). Thirdly, the null hypothesis cannot be rejected for fuzzy probabilities minimum variance model at 1% (5%) significance level for the MDD test and we conclude that this portfolio strategy generates the portfolio composition more or less randomly. To sum it up, the fuzzy probabilities minimum variance model performs slightly worse than Markowitz minimum variance model.

Figure 3
Histograms of Risk Measures from 50,000 Randomly Generated Portfolios with Fitted Gaussian Distributions

Rolling Window Tests in Period 2006-2019
In order to prove that the results are robust to the change of the period considered, the tests are performed on a five-year rolling window basis – four years as the in-sample period and one year as the out-of-sample period. The dataset is the daily-adjusted closing prices of the DJIA components in the period from January 3, 2006, to December 31, 2019. There are only 27 stocks included in our analysis as components Dow Inc., NIKE Inc, and Visa Inc. are excluded due to the incomplete data. The source of the data is finance.yahoo.com. The in-sample period consists always of 1,000 daily returns (approximately four years) and the out-of-sample period consists always of 250 daily returns (approximately one year).
We proceed as follows. First, the portfolio is calculated based on the in-sample period from January 3, 2006, to December 22, 2009. Only Markowitz’s minimum variance portfolio is considered, as it is the best strategy according to the results in Table 1. Second, risk measures, specifically maximum drawdown (MDD), standard deviation (SD) and mean absolute deviation (MAD) are calculated in the out-of-sample period from December 22, 2009, to December 21, 2010. Then, the simple statistical tests for these risk measures are performed and p-values are recorded. The simple statistical test (17) is applied because only one portfolio strategy is analyzed. These three steps are repeated 3,273 times moving the beginning of the periods day-by-day from January 3, 2006, to January 2, 2018 (four-year in-sample period) and from December 22, 2009, to January 2, 2019 (one-year out-of-sample period). The recorded p-values of the simple statistical test are shown in Figure 4. For better clarity, the y-axis is exponential and two significance levels (1% and 5%) are added into the graph.

**Figure 4**
P-values of Bias-free Test for Selected Risk Measures Considering Different Out-of-Sample Periods

![Graph](source: own calculation)

Mixed results can be seen from the figure 5. First, the strictest statistic is based on MDD. For this measure, there are long periods in which the strategy does not lower the risk in the out-of-sample period efficiently (it is about 50% of the analyzed period).

Secondly, SD and MAD behave similarly, although better results are obtained applying SD. This can be explained by the fact that SD (and not MAD) is minimized in-sample. According to this criterion, the strategy does not lower the risk in the one-year out-of-sample periods from December 11, 2012, to July 18, 2013 (January 2, 2013 – May 28, 2013) and from July 1, 2016, to February 2, 2017 (November 7, 2016 – January 12, 2017) at 1% (5%) significance level. It can be seen that for a 1% (5%) significance level the period of inefficiency is relatively short – around 11% (6%) of the total analyzed period.

**Discussion**
In the paper, an alternative approach is proposed to evaluate the efficiency of the portfolio optimization strategies. The approach is based on statistical inference
methodology, i.e. it statistically tests whether the out-of-sample performance is non-random.

The proposed test statistics are close to the normal distribution, thus also the classical t-test can be applied, however, the mean and standard deviation of the test statistics must still be estimated numerically. Comparing the test statistics in the case of single and multiple analyzed strategies, it was found out that the bias-free statistics are shifted to the left. This finding is in line with the explanation of the bias due to the data snooping provided by Aronson (2011). Both in the paper and in the book the test statistics are shifted in the favorable direction of the considered performance measure – in the paper risk measures are shifted to the left as we consider the minimizing performance measures while according to Aronson (2011) the annualized return is shifted to the right as it is maximizing performance measure. It confirms the need to consider the data snooping bias when analyzing the historical performance of portfolio strategies by investors. This phenomenon was already described by White (2000) and well explained by Taleb (2007) under the term survivorship bias.

Based on the presented results, it was confirmed that minimizing the variance of portfolio return in-sample also lower the out-of-sample risk measures. Thus, for investors seeking the minimum risk portfolio, it is worth analyzing the distribution of historical returns and constructs a minimum variance portfolio. This finding is in contradiction with the findings of DeMiguel et al. (2009), who found that none of the strategies, which they analyzed, is persistently better than the 1/N strategy. Thus, it seems that when focusing solely on the risk, compared to the performance ratios in the mentioned study, the strategies are efficient.

The advantage of the proposed approach is that it is stricter than the simple comparison with the benchmark. It is illustrated in the empirical part – maximum drawdown of fuzzy probabilities minimum variance model is lower than that of the index and 1/N strategy, but its efficiency cannot be statistically accepted at a 1% significance level. Also, the quantity of analyzed strategies is considered, thus, avoiding data snooping bias.

The disadvantage of the approach is its computational complexity as a huge quantity of random portfolios must be simulated and their historical performance must be evaluated.

Conclusion

In the evaluation of strategy portfolio performance, the simple and straightforward way is to test whether the strategy outperform the benchmark. This approach answers the question of whether and how much the analyzed strategy overperformed the benchmark in one particular period, but it does not say whether the overperformance is high enough to be considered as significant or whether it is just due to the randomness in data and luck. In the paper, an alternative approach based on the statistical test is proposed in order to evaluate the efficiency of the portfolio optimization strategies. Based on this approach the statistical significance can be confirmed.

The presented methodology considers only one performance measure – in the paper, the risk minimization is considered. This can be limiting and further research should address the question of how to statistically test strategies aiming at two goals, e.g. minimizing the risk while assuring some minimum expected return.

The goal of the paper is to propose and illustrate the test statistics calculation considering possible data snooping bias. The empirical paper studying more strategies as well as more performance measures should follow so that the findings can be easily generalized. The choice of DJIA index as the dataset was due to the easy availability
of the data considering dividends and splits. More markets and periods can be considered.

References


About the authors

Aleš Kresta is an Associate Professor at the Faculty of Economics, VSB – Technical University of Ostrava, Department of Finance. His main research interests are risk estimation and backtesting, portfolio optimization, financial time series modeling, soft-computing, and other problems related to quantitative finance. He is actively engaged in the number of science projects and can be contacted at ales.kresta@vsb.cz

Anlan Wang is a Ph.D. student at the Faculty of Economics, VSB – Technical University of Ostrava, Department of Finance. Her main research area and the topic of her dissertation thesis are problems related to the portfolio optimization. She can be contacted at anlan.wang@vsb.cz
Improving Mental Wellbeing in Organizations with Targeted Psychosocial Interventions

Dean Lipovac
InnoRenew CoE, Izola, Slovenia
Andrej Marušič Institute, University of Primorska, Koper, Slovenia
László Hajdu
InnoRenew CoE, Izola, Slovenia
FAMNIT, University of Primorska, Koper, Slovenia
Institute of Informatics, University of Szeged, Szeged, Hungary
Sølvi Wie
Norwegian University of Life Sciences, Ås, Norway
Anders Q. Nyrud
Norwegian University of Life Sciences, Ås, Norway

Abstract

Background: Mental wellbeing of employees is crucial for successful organizations. Psychosocial interventions that target highly contagious individuals (i.e., individuals that can ‘transmit’ their wellbeing to others) could efficiently improve overall wellbeing in the workplace. Objectives: Using the magnitudes of effects observed in existing studies on psychosocial interventions and the contagion of mental wellbeing, we aimed to examine how the wellbeing of a group (based on WHO-5 Well-Being Index scores) changes if interventions are provided to highly contagious people instead of randomly selected individuals. Methods/Approach: Based on the data on mental wellbeing of 414 nursing home employees, we created a social network that includes individual levels of wellbeing and the strength of the connection between people. Simulation-based influence-maximization was used on the network and interventions were provided to either contagious or randomly selected individuals. Results: Overall, mental wellbeing of the group increased slightly more when individuals had received a simulated psychosocial intervention in order of contagiousness compared to the cases in which interventions were provided to randomly selected individuals. Conclusions: Selectively targeting highly contagious individuals could be an efficient approach to improving wellbeing in organizations, especially in social contexts, where the contagion of mental wellbeing is likelier.

Keywords: mental wellbeing, network science, social contagion, infection model, influence maximization

JEL classification: C6

Paper type: Research article

Received: Jan 31, 2020
Accepted: Jul 6, 2020


DOI: 10.2478/bsrj-2020-0017
Introduction
Mental wellbeing of employees is critical for the long-term success of an organization. Poor mental wellbeing in the workplace can lead to undesirable outcomes, including absenteeism, loss of productivity, and increased health insurance costs (Danna et al., 1999). It is not surprising that various attempts have been made to improve mental wellbeing in organizations. These approaches can be grouped in organisational-level and individual-level interventions. The former group strives to improve physical environment (e.g., decrease noise), work time conditions (e.g., pace of work), and organisation conditions (e.g., structure of hierarchy) (Montano et al., 2014). The latter group aims to equip individuals with knowledge and skills to better cope with work conditions (e.g., stress management classes) (LaMontagne et al., 2007).

While both approaches are valuable, they each bring their own set of obstacles. Organizational-level interventions are advantageous in simultaneously addressing the entire group of employees, but they often have little or no effect (Briner & Reynolds, 1999; Montano et al., 2014). On the other hand, interventions aimed at individuals (particularly cognitive-behavioural programmes) can reliably lead to significant positive changes but are less efficient, as they often need to be administered over several weeks in either small groups or one-on-one (Van der Klink et al., 2001; Richardson & Rothstein, 2008). Despite their effectiveness, sizeable costs required to provide such interventions to all employees might discourage organizations in offering them.

In such cases, a potentially valuable option is to offer only a limited number of individual-level interventions but in a way that could benefit even individuals that themselves do not receive an intervention. This could be achieved by targeting individuals selected based on their ability to “infect” mental wellbeing of other individuals with their own. The approach thus suggests exploiting the phenomenon of mental wellbeing contagion – the observation that mental wellbeing of a particular individual can influence other individuals (Eisenberg et al., 2013). Considering this, a psychosocial intervention could not only improve wellbeing of a highly contagious individual but also positively affect surrounding persons.

The mechanisms behind the contagion of mental wellbeing are numerous and in complex interaction, among them are social comparisons, collaborative development of negative interpretations of recent events, and spreading of (unpleasant) affective states (i.e., core affect, emotions, and mood) (Eisenberg et al., 2013). As an example, consider how affective states can be involved in the contagion process. Unpleasant emotions, such as anger, fear, or sadness, can be “transmitted” between individuals, because people tend to unconsciously mimic facial expressions, voices, movements, and behaviours that can all influence affective states (Hatfield et al., 1993). Chronic experience of such unpleasant affective states (and the lack of pleasant emotions) could contribute to developing mental disorders (Fredrickson, 2000; Fredrickson, 2001; Fredrickson et al., 2003).

The effects of contagion can expand beyond influencing the wellbeing of other group members and can influence group dynamics as a whole, including the attitudes and behaviours of work teams. It has been shown, for example, that when a trained confederate successfully “infected” experiment participants with pleasant affective states, the cooperation between team members increased and conflict decreased (Barsade, 2002). Clearly, transitory affective states seem likelier to spread between individuals than more stable and enduring states of mental wellbeing. Yet it is important to keep in mind that prolonged subtle effects (e.g., increased sadness) could add up to a substantial overall effect (e.g., symptoms of depression).
(Fredrickson, 2000). Indeed, several studies have observed that the overall mental wellbeing of an individual is influenced by the mental wellbeing of surrounding people (Fowler & Christakis, 2008; Rosenquist et al., 2011; Eisenberg et al., 2013).

These findings imply that the contagion of mental wellbeing could be utilized to increase wellbeing of a larger group of people by targeting only select few individuals. Considerably improving mental wellbeing of the most contagious people could be a more efficient approach to improve overall wellbeing of the entire personnel, when compared to directly but slightly improving wellbeing in each employee (as could be achieved with certain organisational-level interventions).

The first step in this approach is identifying highly contagious people. The contagiousness of individuals depends on many factors, both personal and contextual. Important personal characteristics include contagion ability (e.g., emotional expressiveness) and susceptibility (Clarkson et al., 2020). Contextual factors include, for instance, the nature and amount of time individuals spend together. Supervisors are an obvious example of individuals who might be especially prone to being contagious, as they tend to be important in lives of their subordinates and ordinarily have many social connections (Coenen & Broekens, 2012; Eisenberg et al., 2013). Providing psychosocial interventions to such highly contagious people might disproportionately improve the mental wellbeing of the surrounding group of people.

Our objective is to examine if, at least in theory, selectively targeting highly contagious individuals with psychosocial interventions can be an efficient solution to improve overall wellbeing of a larger group of people. We will explore this by running social network infection simulations based on empirically derived effect sizes representing real-life effects of psychosocial interventions and the degree of mental wellbeing contagion. The simulation of the infection process can show if the overall wellbeing of the entire group is disproportionately improved when highly contagious people are targeted with psychosocial interventions (compared to randomly selected individuals). We hypothesise that the mental wellbeing of the entire group of people will improve to a larger degree when the simulated intervention is provided in the order of contagiousness (highly contagious individuals receive it first) instead of random order.

**Methodology**

The proposed methodology might be valuable in optimizing wellbeing of large groups, by exploring how the mental wellbeing of all people in the group changes in response to providing psychosocial interventions to different individuals. It is important to point out that the extent of potential changes in wellbeing relies heavily on the input parameters (e.g., degree of mental contagion), which could substantially differ between social contexts. Thus, although the approach will be presented through empirical data, we would like to emphasize that the method might be useful and worth exploring in other contexts with different parameters, such as different characteristics of individuals (e.g., age, gender, personality) and the environment (e.g., proximity of other people).

As a first step, we created a social network based on the data collected on nursing home employees. From the existing empirical studies, we then selected the effect size of the most effective individual-level intervention in organizations to serve as the effect size of the hypothetical psychosocial intervention provided in our simulation. Similarly, we selected an empirically derived effect size representing the degree of mental wellbeing contagion. These data were used by a simulation model that aimed to improve the overall wellbeing of the entire group of employees by providing a psychosocial intervention to the most contagious people that had been selected.
based on several parameters. The overall wellbeing score resulting from this simulation was compared with the score from the simulation in which individuals receiving the psychosocial intervention were selected at random. Each step is presented in more detail below.

Data collection and transformation
We collected the data on 414 employees from 14 nursing homes in Norway, who completed the survey capturing demographic data, work-related information (e.g., occupation, years working, working hours, shift work), and levels of wellbeing.

We used only the data from participants that had completed the questionnaire assessing wellbeing and who, based on the assumptions of our simulation model, had at least one social connection. These conditions were met by 278 people (268 women), with the mean age of 46.94 years (from 19 to 70; SD = 11.375). Most persons were employed as nurses and auxiliary nurses (235), followed by other healthcare workers (24), supporting staff (14), and managers (3).

Wellbeing was assessed with the WHO-5 questionnaire (WHO, 1998) that asks five questions pertaining to the subject’s last two weeks (e.g., “I have felt cheerful and in good spirits.”). Subjects answered each question on a six-point Likert-type scale (0 = “At no time”, 5 = “All of the time”). The results for one item of the questionnaire (“I have felt calm and relaxed.”) were missing in our data, so we calculated the final score from the remaining four items. We summed the values of responses to obtain the raw score and then rescaled it to obtain a percentage score ranging between 0 and 100 (larger number represents higher levels of wellbeing). In our sample, the mean percentage score on WHO-5 was 68.09 (SD = 17.17). Percentage score is recommended when changes in wellbeing are monitored and this score is used in the results and discussion section. For the purposes of the simulation, however, the score was first divided by 100 to obtain values between 0 and 1 and then reversed, so the values closer to 0 represent higher levels of wellbeing. This reversal was necessary due to the nature of the infection model simulation, which is described in the following sections.

Effect sizes used in the simulation
Individual-level intervention effect size: A meta-analysis of various individual-level interventions in organizations reported that cognitive-behavioral programmes produced the largest average effect size (Cohen’s d (standardised difference between two means expressed in SD) = 1.1154) for a combined group of mental wellbeing outcomes that included measures of stress, anxiety, mental health, and work-related outcomes (e.g., work satisfaction, motivation, perceived control) (Richardson & Rothstein, 2008). This effect size was incorporated in our model; on average, every employee targeted by an intervention had their wellbeing score increased by 1.1554 multiplied by the standard deviation of the WHO-5 percentage score rescaled between 0 and 1 (in our case, SD = 0.172). To approximate varying effects expected in real-life, the effect size of the intervention provided to each employee varied according to the normal distribution with the mean of 1.1554 and standard deviation set arbitrarily at 0.10.

Mental wellbeing contagion effect size: Among the identified studies examining mental wellbeing contagion (Fowler & Christakis, 2008; Rosenquist et al., 2011; Eisenberg et al., 2013), we selected a study from Eisenberg et al. (2013) that was especially careful in controlling several sources of bias and, correspondingly, arrived at a lower estimate of the mental contagion effects compared to other studies (β = 0.053, 95% CI = [0, 0.12]). Although this effect size is based on specific anxiety items
from the K-6 instrument assessing general psychological distress (Kessler et al., 2003), the captured construct has been shown to have a considerable overlap with the construct tapped by WHO-5 (e.g., Downs et al. 2017), on which we base our simulation. For our simulation, the selected effect size indicates that the wellbeing score of a neighbour in a social network will increase for 0.053 multiplied by the standard deviation of the WHO-5 percentage score rescaled between 0 and 1 (SD = 0.172). To allow for varying degrees of contagion based on the strength of social connections (e.g., amount of time spent together), we instructed our simulation model to select a value from the 95% confidence interval [0, 0.12] of the abovementioned effect size, where the stronger social connection received a higher value. The resulting values that are used in the simulation thus lie on the interval between 0 (i.e., 0.172 * 0) and 0.021 (i.e., 0.172 * 0.12).

Network modelling

General model: To define the network formally, let $G(V, E)$ be the network where $V$ is the set of the nodes (in our case the set of employees) and $E$ describes the set of edges (the connections between the nodes). Let $0 \leq p_{v_1,v_2} \leq 1$ be the edge probability between $v_1$ and $v_2$, where $v_1, v_2 \in V$. This probability represents the connection strength between two nodes; 1 signifies the strongest connection and 0 indicates there is no connection. In addition, let us define the properties of a node:

- Let $s_v$ be an initial probability, representing the reversed and rescaled WHO-5 percentage score of the node $v$.
- Let us call $s_v^{\text{intervention}}$ the intervention probability of the node $v$, which describes the reversed WHO-5 score of the employee after the intervention, therefore $s_v^{\text{intervention}} \leq s_v$.
- $w_{v_1}, w_{v_2}, w_{v_3}, \ldots, w_{v_n}$ a list of real-life based properties of the $v$ node.

In case of both nodes and edges, the initial probability comes from a real-life based property (i.e., our data) of the node (i.e., employee). In the following section, we describe the network created from the collected data.

Model from the collected data: To give an instance of a general model, we used the collected data from the nursing homes. Since we did not have information about the real connections between the employees, we created the connection structure based on similarities of different individuals. In the network, every employee represented by a node and the connections (i.e., edges) between them were arbitrarily assigned if:

- They were employed at the same nursing home
- They had the same occupation (e.g., nurse)
- The age difference between them was not greater than 20 years.

The strength of the connection was computed based on properties of the corresponding employees, resulting from the sum of the following properties:

- Age difference: Difference in age of the corresponding employees, where lower age difference increases the connection strength, scaled between 0 and 0.33
- Matching work shifts: The probability of employees meeting during work due to similar work schedules, where matching shifts increase the connection strength, scaled between 0 and 0.33
- Weekly working hours difference: The probability of employees meeting during work due to similar working hours, where a similar number of working hours increases the connection strength, scaled between 0 and 0.33
The final edge weight is the sum of the scaled values, so a number between 0 and 1, multiplied by a random number between 0 and 0.021, which represents the extent of mental wellbeing contagion (the process of arriving at this value is described in a previous section). (It is important to point out that the model is flexible enough to be used with different connection strengths; to compute the edge probabilities based on different edge attributes, work from Bóta et al. (2014) provides a good example.)

The resulting network had 289 nodes and 731 edges. A sample of the network is presented in Figure 1. Nodes, representing employees, are coloured based on the rescaled and reversed WHO-5 scores; the width of the edges increases with the edge weight (i.e., probability of the mental wellbeing contagion).

Figure 1
A Sample of the Network

Source: Authors’ work

Infection model and optimization

The basic idea of infection models is to simulate the spread of a virus, information, or any other entity on a social network. In our case, this entity is human mental wellbeing (reversed score), as it can be contagious in a similar way as other effects on the network (e.g., Eisenberg et al., 2013). The basic concept of the problem was proposed by Domingos & Richardson (2001) and by Granovetter (1978), where the idea and the objective of the research was to improve the efficiency of viral marketing. The exact mathematical description and theoretical background of a problem was introduced by Kempe et al. (2003, 2005).

To represent employee connections and the spreading of (reversed) wellbeing levels in the workplace, we used an extended Generalized Independent Cascade model (Bóta et. al., 2013), where initial probabilities on the nodes are also defined. Chen et al. (2010) proved that the exact computation of the node probabilities is P#-complete, therefore, mostly heuristics are used. However, with simulation, any precision level can be reached (Kempe et al., 2003).

If the previously defined network is given with all of its properties, let $f_{v}$ be the final reversed wellbeing score of the node $v$ after the simulation, and value $a(V)$ the sum of the final infection for each node, which was computed by the Complete Simulation (Bóta et al., 2013). The difference between the mentioned models and our model is
that in our case every single node can become an infector in the first step of the algorithm. The method takes the following inputs:

- \( G(V, E) \) previously defined social network
- \( N \subset G(V) \) employee set without a psychosocial intervention
- \( I \subset G(V) \) employee set with a psychosocial intervention
- \( k \) sample size

It is important to note that \( N \cap I = \emptyset \) and \( N \cup I = G(V) \). The pseudocode of the simulation is presented in Algorithm 1.

**Algorithm 1: Complete Simulation in Generalized Independent Cascade**

```plaintext
1 INPUT: G(V, E) network, N \subset G(V), I \subset G(V), sample size k
2 j ← 0
3 FOR ALL \( v \in V : f_v = 0 \)
4 WHILE j < k
5 FOR ALL \( v \in I \) set up \( s_v \) where \( s_v = s_v^{\text{intervention}} \)
6 \( A_0 \leftarrow \) initial infectors based on the \( s_v \)
7 FOR ALL \( e \in E : \) set the state of the edge to active or passive based on \( p_e \)
8 Modified DFS from all \( v \in A_0 \)
9 IF the visited node \( n \) is reachable from \( v \)
10 \( f_n \leftarrow f_n + 1 \)
11 END IF
12 \( j \leftarrow j + 1 \)
13 END WHILE
14 FOR ALL \( v \in V : f_v = \frac{f_v}{k} \)
```

The algorithm generates \( k \) different instances of the network by deleting and keeping edges and creating infectious and non-infectious employees, using the edge and the node probabilities. The simulation is used to compute the final reversed wellbeing score of one possible scenario, where \( I \) and \( N \) are given; that is, with one possible employee set receiving the intervention. First, we run a reference simulation to get the final infection in case if \( I = \emptyset \) (no intervention). The optimization environment computes the possible intervention scenarios and maximizes the overall wellbeing by minimizing the scores of the nodes (i.e., reversed wellbeing score) with the set of employees receiving the intervention. Figure 2 shows the basic frame of the system with example values.
In this case, the intervention 2 was chosen, since the $I_2$ set of employees receiving intervention reached the maximal reduction in reversed wellbeing score in the model. After the intervention, the model will decrease the score of each employee in the $I$ set and their local neighbourhood, since the employee receiving intervention will now have a lower probability to spread its “reversed wellbeing”. A similar model, where the negative spread was considered, was published by Tóth (2016). To optimize the influence of the intervention in the social network, we used the infection maximization.

In the infection maximization problem, the main objective is to maximize the spread with an initial infector set. The original infection maximization problem was published by Kempe et al. (2003), where they proved the NP-hardness of the problem. Due to the hardness of the problem, we used a heuristic to maximize the intervention effect on the network. The most efficient and widely used method with a guaranteed solution is the greedy method. In the same paper, Kempe et al. (2003) proved that the greedy method gives at least 63% of the optimum. In our case, the greedy method maximizes the difference between the reference simulation and the actual solution; therefore, to use the greedy method for our research problem, we had to change certain parts of it. The pseudocode of the proposed method for the optimization is the following:

**Algorithm 2:** Greedy Method to minimize the negative wellbeing level of the employees

1. **INPUT:** $G(V, E)$ network
2. **OUTPUT:** Ordering of the employees based on negative wellbeing reducing potential
3. $I \leftarrow \emptyset$
4. $N \leftarrow G(V)$
5. $R \leftarrow \sigma(V)$ reference simulation
6. **WHILE** $|I| \neq |G(V)|$
7. $I = I \cup \arg \max_{I \subseteq G(V)} (R - \sigma(I \cup N))$

The greedy algorithm increases the size of the $I$ by one in every iteration, by selecting the employee that decreases the global reversed wellbeing score the most. To show the optimal number of the employees receiving the intervention, it is possible to find a threshold where the global negative wellbeing will stop decreasing significantly.
Results and discussion

We compared the changes in wellbeing of the entire group of people between two instances: when simulated interventions were provided either in order of contagiousness or in random order. Figure 3 displays the mean increase in WHO-5 percentage score per person after the hypothetical intervention was provided to different number of individuals in the group (compared to the reference point scores without the intervention). The figure separates the scores based on the order in which the intervention was administered; in one case, the order of individuals provided with the intervention was random, in the other, the intervention was first administered to highly contagious people (i.e., people who, after receiving the intervention, made the largest positive impact on the wellbeing of the entire group of people). In both cases, the scores steadily increase until all individuals receive the intervention, where the average increase becomes similar to the effect size of the intervention used in the simulation. When the intervention was administered to highly contagious people first, the increases in scores were generally larger when compared to the scores following random administration of interventions. This represents the effect of contagion: although, on average, the score of each individual increased (i.e., improved) the same after the intervention, some persons were better able to spread that improvement to others, due to their contagiousness.

Figure 3
Mean Increase in WHO-5 Depending on the Order of Intervention Administration

Some of the results from Figure 3 are presented in more detail in Table 1.

Table 1
Comparison of the WHO-5 Percentage Score Mean Increase per Person

<table>
<thead>
<tr>
<th>Number and percent of interventions</th>
<th>Mean increase in score after random administrations</th>
<th>Mean increase in score after targeted administrations</th>
<th>Difference between targeted and random</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 (3.6%)</td>
<td>0.74</td>
<td>0.83</td>
<td>0.09</td>
</tr>
<tr>
<td>20 (7.2%)</td>
<td>1.43</td>
<td>1.61</td>
<td>0.18</td>
</tr>
<tr>
<td>50 (18.0%)</td>
<td>3.55</td>
<td>3.94</td>
<td>0.38</td>
</tr>
<tr>
<td>100 (36.0%)</td>
<td>6.85</td>
<td>7.64</td>
<td>0.79</td>
</tr>
<tr>
<td>200 (71.9%)</td>
<td>13.58</td>
<td>14.64</td>
<td>1.06</td>
</tr>
</tbody>
</table>

Source: Authors’ work
The table 1 displays the mean increase in WHO-5 percentage score per subject for selected numbers of interventions provided to the group. For example, after 20 subjects received the simulated intervention, the percentage score in the entire group of subjects increased, on average, by 1.61 per person, when intervention administrations were ordered by contagiousness, which is 0.18 larger than the average increase per person following randomly administered interventions. In this case, selectively targeting contagious individuals is thus responsible for a 0.18 increase in WHO-5 percentage score per person, all else being equal.

The observed differences in mean scores between random and targeted intervention administrations are small. This is not surprising, given that our model was based on a relatively large effect size following an intervention, but only a fraction of that improvement was expected to be transmitted between individuals, due to the small effect size of mental wellbeing contagion that was incorporated in the simulation model. However, in contrast with the intervention effect size that was based on a meta-analysis considering several studies, the contagion effect size was derived from a single study (Eisenberg et al., 2013), due to lack of relevant research.

Despite the robustness of that study, there are reasons to assume that the contagion effect could be larger. As is generally the case, a single result can rarely be a definitive answer on the topic. Indeed, other studies researching mental wellbeing contagion in other contexts have arrived at considerably larger effect sizes (although, admittedly, in those studies the potential for bias was higher) (Fowler & Christakis, 2008; Rosenquist et al., 2011). Another important aspect is the social context. Our model used an effect size derived from a study examining contagion in college roommates. In different contexts, however, the contagion effect could be larger, as it may depend on various individual and interpersonal factors (Coenen & Broekens, 2012). Difference in social status is one of the factors increasing the degree of contagion; contagion is likely more pronounced when passing between a higher social status individual and one with a lower status (e.g., between a supervisor and a subordinate) (Coenen & Broekens, 2012). Presumably, such asymmetries in social status are more common in many hierarchically structured organizations than in relationships between college roommates, on which our contagion effect size was based. If the contagion of mental wellbeing is indeed more pronounced in certain organizations, our simulation model could show that the overall effects of contagion are considerably larger compared to the effects reported in this article. The effects could be particularly pronounced, for example, in highly hierarchical organizations, where supervisors hold especially high status compared to their subordinates (presumably leading to larger contagion effects) while at the same time supervising many employees (i.e., there are numerous recipients of the contagion effects). An organization could identify such potentially highly contagious individuals with a simulation model, assuming appropriate data is available or can be collected. Interventions targeted at such individuals could lead to a relatively large improvement in the wellbeing of the entire group.

Limitations
The model used in our study could represent real-life more closely if additional data would be considered as a moderator of the contagion effects. Since it was shown that various individual and interpersonal factors may influence the degree of contagion (Coenen & Broekens, 2012), taking these data into account is crucial. For example, females might be more susceptible to contagion, and contagion might be more pronounced between people with similar attitudes on various topics (e.g., religion, sports, death penalty) (Coenen & Broekens, 2012). The model could be additionally strengthened after an empirical evaluation (e.g., Tsai et al., 2011).
Although beyond the scope of this article, it is worth pointing out that providing interventions to a subset of individuals might provide practical hurdles that are challenging to overcome. For example, individuals that are selectively offered a psychosocial intervention might receive the offer negatively (due to the stigma related to implied issues with mental wellbeing), while individuals not offered the intervention could react negatively as well (due to perceiving the lack of offer as unjust).

**Conclusion**

Improving mental wellbeing is a challenging task, especially when attempting to improve wellbeing of a large group of people. Interventions can often only slightly improve the overall wellbeing in the workplace. Organizational-level interventions can address the entire personnel simultaneously, but provide little effect, while interventions targeting individuals provide considerably larger effects, but can require substantial resources in terms of time, effort, and money. Either way, regardless of which intervention type is selected, many individuals will be in need of additional support. Clearly, then, the efficiency of interventions is of interest. One way to increase the efficiency of existing interventions, is to provide them to specific individuals – those who are highly contagious and can ‘transmit’ their mental wellbeing to other people. In effect, those individuals can make the most of the intervention, as far as the overall wellbeing of a group is concerned.

We have seen, however, that the effects of the mental wellbeing contagion can be relatively small and that singling out individuals, who are selected to receive the intervention, might bring additional challenges. Yet it is important to keep in mind that in different contexts the contagion effects could be larger and that issues stemming from singling out individuals might be well worth the price, considering the subsequent improvement in overall wellbeing of the group. We have shown that, at least in principle, the wellbeing of a group can be more efficiently improved if highly contagious people are targeted with interventions. As this approach could improve the efficiency of psychosocial interventions, leading to improved wellbeing in organizations, it is worth further theoretical and empirical exploration.

**Acknowledgments**

The authors gratefully acknowledge the European Commission for funding the InnoRenew CoE project (Grant Agreement 739574) under the Horizon2020 Widespread-Teaming program, the Republic of Slovenia (Investment funding of the Republic of Slovenia and the European Union of the European Regional Development Fund), and the Slovenian Research Agency ARRS for funding infrastructure program IO-0035.

**References**


About the authors

Dean Lipovac completed a master’s degree in applied psychology at the Faculty of Mathematics, Natural Sciences and Information Technologies, University of Primorska (UP), in Koper, Slovenia and is currently a PhD student. He is an assistant researcher at the InnoRenew CoE and Andrej Marušič Institute (UP). His main research interest is the connection between the built environment and human mental health. His work is focused on researching how different materials used in indoor design influence physiological, emotional, and cognitive indicators of well-being. The author can be contacted at dean.lipovac@innorenew.eu

László Hajdu is an assistant researcher at InnoRenew CoE, at University of Primorska, Faculty of mathematics, Natural Sciences and information technologies, and PhD Student at the University of Szeged. He completed his Bachelor’s and Master’s degree in Computer Science at the University of Szeged. His main research interest is network science and graph algorithms. His work is focused mostly on Community Detection, Infections in networks, Banking Data Analysis, and Network Science based optimization methods. The author can be contacted at laszlo.hajdu@innorenew.eu

Solvi Wie, MSc, is a Ph.D. student in Wood Technology at the Faculty of Environmental Science and Natural Resource Management, Norwegian University of Life Sciences (NMBU). She received MSc in Public Health Science at the Faculty of Landscape and Society, NMBU, with the thesis “Associations between work-related psychosocial risk factors and musculoskeletal complaints in Norwegian aircrew”. Her main research interest is the effect of nature, environment, and surroundings on human health; currently she is investigating the relationship between wood in buildings and occupant experience and health. The author can be contacted at solvi.wie@nmbu.no

Anders Q. Nyrud, Dr, Scient, is a Professor in Wood Technology at the Faculty of Environmental Science and Natural Resource Management, Norwegian University of Life Sciences (NMBU). Professor Nyrud has a background from research and consulting in the Norwegian wood processing industries. His research focuses on various aspects related to the use of wood, in particular the relationship between raw material properties, industrial production processes, and market requirements for final products and their attributes (i.e., functional, aesthetical and/or psychological attributes). The author can be contacted at anders.qvale.nyrud@nmbu.no
Selection of Project Managers: An Overview

Marija Šiško Kuliš
University of Rijeka, Faculty of Economics and Business, Rijeka, Croatia

Abstract

Background: The project manager choice is one of the most important, complicated and multi-layered decisions in project management. Although the competence of a project manager is the subject of numerous studies, mostly in the field of economic sciences, there are still relatively few studies dealing with project manager selection. Objectives: The aim of this paper is to provide a useful overview of research on approaches, models, techniques, and competencies during the process of selecting project managers, in order to improve understanding an effective process of selecting project managers from academic researchers and practitioners’ point of view. Methods/Approach: This article is a scientific review of previously published studies that are linked to competencies of a project manager and the process of project manager selection according to the traditional and the modern approach. Results: The process of selecting project managers is not sufficiently investigated in Croatia, while most of the research is focused to traditional approach. Conclusions: In this work, we propose a combination of the traditional and the modern approach to the selection of project managers, which would be based on the multicriteria decision making.

Keywords: manager, project, approach, competence, model, criterion
JEL classification: L21, M21, M 54

Introduction

The history of human achievement is marked by projects as unique, one-time, time-limited, goal-oriented creative processes, from the creation of the Bible, the construction of the Egyptian pyramids and the Great Wall of China, space conquest projects, new energy sources, new materials, biotechnology projects and new institutions. Other less exposed projects that have guided and are directing the development of humanity (Tainter, 2007). Likewise, today’s time is marked with projects. Moreover, the trend of increasing the number of projects is evident in the scientific, economic, social and political environment (Barnes, 1988). However, most of these projects fail, the project results are mostly devastating (El-Saaba, 2001; Faniran et al., 2000). It is alarming that, according to data from the relevant literature: 52.7% of projects fail to close on time and it turns out that only 30% of projects are carried
out so that they meet all projected goals (Nahod, 2014, Uhlir, 2011). The
aforementioned well determines Cobb’s Paradox: „We know why projects fail. We
know how to prevent their failure. So why do they still fail?” (Cobb, 1995).

the critical project success factors are: clearly defined project goals, project sponsor
strategy, project coverage, technological complexity, simultaneity, contracting
strategy, project environment, top management support, geophysical conditions and
human resources competence. Among them, the competence of the project
manager should certainly be emphasized as a critical factor of project success (Morris
& Pinto, 2007; Meredith & Mantel, 2003; Muller & Turner, 2007; Wang et al., 2005;

The project manager is accountable for the project success (Afshari et al., 2018),
and according to global predictions, the most important job of the 21st century will
be the project manager (Stewart, 1999). Therefore, his choice is the prime decision in
project management (Varajão & Cruz-Cunha, 2013; Rashid et al., 2018) and the topic
worth exploring (Smith, 2013a). From the aspects of the project manager selection, it
should be emphasized (Sadatrasool et al., 2016):

- The project manager has special responsibility for fulfilling all defined project
goals inside the prescribed deadlines and the set budget.
- He manages the project every day. Project managers contributors, with
responsibilities for the project certain parts, can significantly support it without
compromising its credibility and responsibility.
- The project manager should demonstrate competencies, which include tacit
and explicit knowledge, skills and proportionally experience with the scope,
complexity and project risks.

For the project manager to achieve authority and/or reputation the towards
project team and stakeholders, essential is to pass the project manager selection
process. It is an internal or public selection and selection process. Credibility should be
professional or administrative (Omazić & Baljkas, 2005). Professional credibility means
that the project manager does not have to be an expert, nor does he have to know
more in all areas of activity than any team member does; he only has to understand
the technological process of the project. Administrative credibility refers to the fact
that the project manager should be achieved that the project proceeds according
to the schedule, inside the budget and within the deadline frame in which it is
provided, and should provide key resources for project development.

Project management is not easy and is demanding and stressful for the project
manager because it implies the need for more comparative competencies. Selecting
the best project manager is a complicated process because there are many topics
to consider. The process of weighting the criteria relative to the project manager
selection is particularly sensitive. It is necessary to ensure that the selected project
manager has a balanced relationship of knowledge, experience and personality traits
(Varajão & Cruz-Cunha, 2013). This has stimulated interest in developing the body of
knowledge and certification procedures that can be used to assess, recognize, and
as a guide to developing project management competencies (Crawford, 2000).

However, when it comes to the results of relevant researches, there is a certain
imbalance here: on the one hand, searching databases such as Scopus&Web of
Science, EconLit, etc. Numerous research addressing desirable project manager
attributes can be found (Meredith & Mantel, 2003), including their moderation impact
on project success (Papke-Shields et al., 2010; Tesch et al., 2003). On the other side,
there are only a few types of research about the selection of a project manager
(Smith, 2013a; Smith, 2013b). Besides, recent research on this topic comes mainly from
the field of information technology, sometimes engineering and very rarely from the
field of economics, although the consequences of poor selection of project managers
are first seen in the economic dimensions of project success. The process of selecting
project managers is insufficiently researched and it has consequences on the state of
knowledge for this topic and at practice, especially in Croatia.

The aims of this paper are: (i) to provides a useful overview of research on
approaches, models, techniques, and competencies during the project manager
selection process, (ii) to improve understanding and effectiveness of the process of
selecting project managers from academic research and practitioners point of view,
(iii) to make a good framework for new research in this insufficiently researched
discipline and encourage explorers to explore this topic, (d) to contribute to the
development state of knowledge for this topic and practical implementation in
Croatia.

This article is composed in the following manner. After the introduction, section two
briefly describes the state of knowledge in the field of a topic in Croatia. The third
section focuses on existing studies of (a) Competence of the project manager, (b)
Project manager selection that includes two parts traditional approach and modern
approach - multi-criteria decision making. The last section displays conclusions and
recommendations for future researches.

### Competence of the project manager

The results of numerous studies show that the project manager’s competence is a
project success key factor (Gonzales & Terriquez, 2013). Project managers are
classified as stars, creative experts, decision-makers, insensitive pragmatists (Hauschildt et al., 2000). An effective project manager should be above average
intelligent and have exceptional problem-solving skills (Ress et al., 1996). However,
there is no consensus on what competencies a successful project manager should
have. Although some researchers believe that the competencies of project managers
are generic, the prevailing view is that different projects need different competencies.
In this atmosphere, the interest of scientists and business people to determine the
critical and key competencies of project managers that will imply the success of the
project is growing. The internal and external environment of the project is most often
changeable, which requires continuous improvement of the competence of the
project manager (Takey & Carvalho, 2015). A review of research competences of the
project manager is given in Table 1. The emphasis is on projects in the field of
construction, of which the electricity sector is a part.

<table>
<thead>
<tr>
<th>Research</th>
<th>Project manager competencies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Omidvar et al. (2011)</td>
<td>Competencies related to the personality of the project manager: project management, technical competencies, personal characteristics; Job orientation: Targeted performance (compliance with standards); Contextual competences: competences related to the environment client, organization, subcontractors and suppliers, competencies.</td>
</tr>
<tr>
<td>Fraser (1999)</td>
<td>Technical skills, site management and mobilization, assessment and tendering, design of Gantt charts and environments, technical literacy, public relations (PR), the delegation of tasks, conducting meetings, contracting, and technical literacy.</td>
</tr>
</tbody>
</table>
Edum-Folwe & McCaffer (2000)  
Technical skills, mobilization, site management, assessment and public tender, time and environment management (Gantt Chart), technical, presentation and report literacy, decision making, negotiation skills, job delegation, teamwork, IT skills and oratory skills, report literacy, meeting and stress management, public relations, marketing and sales, problem-solving.

El Saba (2001)  
Technical skills, IT skills, coping in unfamiliar situations, job delegation, mobilization, problem orientation, holistic view of the project, project relationship management with industry, public opinion, knowledge of PM methods, tools and techniques, technological skills, objectives orientation, political flexibility, planning, organization, self-confidence.

Odusami (2002)  
Technical (hard) and soft skills, troubleshooting, decision management, teamwork, job delegation, stress resistance.

Frank (2002)  
Character traits and background: education, faithfulness, tacit and explicit knowledge, ambition, intelligence, visionary, analytical, managing people and the environment, be a leader, emotional stability. Professionalism: effectiveness, to have a vision, target-oriented, analytical skills, to be fast, inspired, leadership. Project skills: execution, methodology, initiation, selection, control, time and documentation management. Core competencies of the project manager: honesty, goal orientation, professionalism, analytical skills.

Loo (2003)  
Technical skills, human competencies, team management, stakeholder management, conflict management, motivation, organizational effectiveness.

Pant & Baroudi (2007)  
Communication of team and project stakeholders, interpersonal skills, technical competencies, cognitive abilities to understand situations, organizational effectiveness, flexibility, decision making, problem-solving, trustworthiness.

Tohidi & Jabbari (2012)  
Team motivation, fair attitude towards the environment, leadership, regular conditions, correct attitude towards co-workers, human resources development.

Madter et al. (2012)  
Teamwork, human management and develop their competence, self-confidence, customer orientation, communication ability, interpersonal skills, understanding, conflict and change management, organizational support, looking opportunities for improvement, value management.

Brière et al. (2015)  
Flexibility, stakeholder management, management and communication skills, personality, interpersonal skills, ethics, leadership skills, change management.

Source: Authors’ work

To identify the project manager competencies and to provide guidelines for the continual growth of the basic competencies for project management, 2.

Table 2  
Comparative analysis of the competence framework of the project manager

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Behavioural</td>
<td>6 personal and social</td>
<td>10 personal and social</td>
<td>In three dimensions</td>
</tr>
<tr>
<td>competencies</td>
<td>competencies</td>
<td>social competencies</td>
<td>(constructs): behavioural,</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>managerial and</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>contextual competencies,</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>27 competencies were</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>nominated, e.g.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>leadership.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>They are combined.</td>
</tr>
</tbody>
</table>
Technical competencies are considered “other competencies”, and the PMCD does not address specific competencies. 20 hard competencies are nominated. Technical competencies are related to the integration of design work and production of project results.

<table>
<thead>
<tr>
<th>Technical competencies</th>
<th>20 hard competencies are nominated.</th>
<th>Technical competencies are related to the integration of design work and production of project results.</th>
</tr>
</thead>
</table>

**Management competencies**

<table>
<thead>
<tr>
<th>Knowledge: Knowledge of the project manager about the processes, tools and techniques for project management. Performance: This is the application of project management knowledge. In general, what project manager is capable of achieving with his knowledge?</th>
<th>Practical competencies: fourteen competencies related to the areas of knowledge about projects, programs and portfolios and project management processes.</th>
<th>Among the 27 established competencies, there is a combination of behavioural, management, and contextual competencies. Some of APM’s responsibilities are related to areas of knowledge about project management and project management processes, such as procurement, scheduling and risk management.</th>
</tr>
</thead>
</table>

**Contextual competencies**

<table>
<thead>
<tr>
<th>Contextual competencies are treated as secondary competencies that the PMCD does not deal, but supports their importance within the organization.</th>
<th>Perspective competencies: five competencies linked to the project management: strategy, standards, recommendations and regulations, process structures, management, compliance, supremacy and interest aspect, ethics and cultural aspect.</th>
<th>More than 27 nominated competencies; there is a compound of management, behavioural, t, and contextual competencies. For example, control methods are one of the APM competencies.</th>
</tr>
</thead>
</table>

**Source:** Authors’ work

Relevant international professional project management associations have developed project management guides and project manager certification. Globally, the best known and most numerous are PMI (Project Management Institute), IPMA (International Project Management Association) and APM (Association for Project Management). There are still many national and international associations working on the professionalization of project management by a competency approach. A brief comparison of the project manager competency framework is given in Table 2.

The international associations IPMA and PMI have the head role at Europe and their main goals are to lead the mainstreaming of project management so they have developed their frameworks and procedures for assessing the project manager competence, Moon et al (2018), for certification of project, program and portfolio managers. Certification is following the standard ISO / IEC 17024: 2012 It is deployed by the ISO Committee on conformity assessment and approved by both ISO and the IEC (International Electrotechnical Commission).
Certification of managers carried out in Croatia by subsidiaries of IPMA and PM institutions. Important is to point out that there are more than a million certified project managers worldwide (a number collected from statistics on PMI.org and IPMA.org), according to Farashah et al. (2018). There is an increasingly pronounced trend of increasing certified project managers in Croatia too (Uhlir, 2013).

Managers who have validated their competencies through certifications will certainly lead to better results in less time and at a lower cost than those project managers who are not allowed to validate their competencies with certifications.

**Traditional approach**

Traditionally, potential candidates for project manager position are selected in a three-step process that includes resume review, interview and reference check (Horner, 2010; Smith, 2013a) after which a decision is made on the selection of candidates.

The interview plays a major role in this approach and its main comparative advantage is the value of the personal contact it provides. The primary goal of the interview is to project the candidate’s behaviour in new and unknown situations inside role frame of the project manager. The secondary goal is to inform the candidate about the role he is applying for (Armstrong, 2009).

Recent research shows that interview validity is enhanced by structured interviews that achieve greater validity than unstructured ones (Macan, 2009), as shown by the results of the global researches (Smith, 2013a) which show that project stakeholders are significantly more satisfied with the application of structured interviews in project manager selection, than the classic three-step approach.

As already mentioned, there is a little number of researches related to the project manager selection, and below is a brief overview of such research found in the relevant research databases.

Swanson (1964), this early research showed that the selection process can be understood and described, but did not discuss an approach that could be applied in the process of efficient and effective project manager selection.

Collins (1998) focused his research on selecting a project manager within an organization. The starting point of his research was that the project manager should be mastered technical and managerial skills to be “successful”. As it was assumed that the candidate was already a member of the organization, Collins' research did not include consideration of the recruitment process, within which data were to be obtained to better understand the candidate, such as resume review and verification of relevant references.

Namely, human species cognitive processes and assessments are biased, imprecise, and multifaceted. Traditional methods of choosing leaders are inefficient and ineffective because they neglect the aforementioned (Rashidi et al., 2011).

Smith (2013a) who says that the traditional selection of project managers is usually based on a review and verification of the nominated references, curriculum vitae and interviews hold a similar view. This three-step selection process has not changed for many years. Given the progress in understanding the role of the leader and the influence of the project leader on the success of the project, this selection process is unsatisfactory. Besides, with the traditional approach of selecting a project manager, the weighting of individual characteristics of the project manager may be questionable. The selection process becomes more difficult when there are several qualified candidates. There is also the possibility of disagreement among board members regarding the selection of a particular person, especially when there are multiple qualified project managers. In such cases, a computational system based on
artificial intelligence, which can support the decision-making process, is very useful. (Rashidi et al., 2011).

Horner (2010) the traditional three-step approach to project manager selection is not comprehensive enough to allow the determination of respondents' potential for the project manager role. The traditional three-step approach to project manager selection is mostly inaccurate, biased, is not unique and has a thin accuracy.

More recently, certain researchers have advocated psychometric testing as a model for the project manager selection process, for example, Aretoulis et al. (2009), Muchinsky (1979), and consider it more effective than the interviews of Korres et al. (2003). Namely, experience and hard competencies can be assessed and confirmed by someone's curriculum vitae. However, interpersonal and communication skills are hard to assess from someone's resume. It is necessary to implement specific psychometrics methods and techniques for research, evaluation of personality traits of the candidate for the project manager and thus precisely define his psychological profile. It should be emphasized that not only standard questionnaires are used, but also it is necessary to use relevant statistical methods such as synthesis and analysis method (Muchinsky, 1979).

On the other hand, Wolf (2005) considers it a controversial process with questionable results.

Besides, proponents of psychometric testing ignore the fact that behavioural competencies are also examined during the project management certification process and that such testing could easily become an end in itself. Besides, it could further complicate, prolong and increase the cost of the project manager selection process.

Modern approach - multi-criteria decision making

Advances in information technology over the last decade have shed new light on the project manager selection process. Thus, Afshari et al. (2018) emphasize that the project manager selection procedure should be based on Multi-Criteria Decision Making (MCDM). Data and information obtained by the selection process of the project manager are processed by precise mathematical models, which result in the selection of the most qualified person (Rashidi et al., 2011).

In the field of multicriteria decision-making, there are two types of multicriteria problems from the aspect of describing them with a mathematical model. These are (Tudela et al., 2006; Farahani et al., 2010):

- Multi-Objective Decision Making (MODM) is essentially a mathematical optimization that is effective for a scenario that can be seen as complex but at the same time well-structured problems. Structured in the mentioned context means a known initial and final state. Modelling includes a large number of variant solutions that have obvious limitations.
- Multi-Attribute Decision Making (MADM) or Multi-Criteria Analysis (MCA), which applies to a scenario characterized by the following: complex, complicated and vaguely defined objectives, high uncertainty and instability. Even during the solution process, the very nature of the problem changes, which further complicates the process of its effective solution. This type of problem is nominated as poorly structured problems.
- Multicriteria analysis methods include several methods such as dominance method, max-min, min-max, conjunctive and disjunctive method, lexicographic method, simple additive weighting SAW method (Simple Additive Weighting), VIKOR (Serbian/Croatian, VIšekriterijsko KOmpromisno Rangiranje) TOPSIS method (Technique for Order Preference by Similarity to Ideal Solution).
Multicriteria analysis can be determined as a decision model that includes the following (Hajkowicz, 2009):

- Solutions set (variants which will be classified, ranked and evaluated by the person who has mandatory to make the decision).
- Criteria’s set (mostly multidimensional criteria, which can therefore only be evaluated by different units of measurement).
- Values (evaluation) of each variant according to each criterion.

Multi-criteria analysis is an appraisal method that ranks solution variants and determines the overall evaluation of variants based on a set of pre-set criteria. Here, each variant is evaluated according to each of the set criteria (attribute) using the assigned weight (ponder) (Tudela et al., 2006).

The methodology for applying multicriteria analysis includes the following algorithm (Farahani et al., 2010): analyse multiple solutions, nominate criteria, evaluate solutions according to all criteria, determine the weights of the criteria, ordering and grouping solutions, make sensitivity analysis, and judge and finally decide.

In the project manager selection, the application of multicriteria analysis using Cloud Theory, which is based on a combination of Fuzzy sets, Gray Systems Theory, probability theory and statistical methods, is becoming more and more prominent (Baykasoğlu & Özbakır, 2007; Chen & Cheng, 2005; Lau et al., 2006; Sadatrasoola et al., 2016; Zavadskas et al., 2008). For example:

- SAW - Simple Additive Weighting (Hwang et al., 2007; Sivilevicius et al., 2008);
- TOPSIS - Technique for Order Preference by Similarity to Ideal Solution (Farahani et al., 2010; Varajao and Cruz-Cunha, 2013);
- VIKOR - Compromise Ranking Method (Kosijer et al., 2012; Šarka et al., 2008);
- COPRAS - Complex Proportional Assessment (Šarka et al., 2008, Karbass & Nollet, 2008; Sliogeriene et al., 2009; Datta et al., 2009; Tupenaite et al., 2010);

Figure 1
TOPSIS- basic concept
The following is a brief description of these methods, which are relatively often used in economics, with special emphasis on AHP, which is still most often used in the project managers' selection:

- **SAW** is an additive method, the oldest, by far known and most widely used method. It is based on the integration of criterion values and weights into one size.

- **COPRAS** is used for multicriteria evaluation, maximizing, and minimizing criterion values. This method has a significant advantage over the SAW method: during data processing, i.e., multi-criteria evaluation, a calculation is performed for the maximum and minimum value of the observed criterion.

- **TOPSIS** is developed by Yoon and Hwang (1995). Optimization is done by looking for a solution that is the shortest way from the best solution and the longest away from the worst solution, as shown in Figure 1 (Balioti et al., 2018).

- Serafin Opricović first developed **VIKOR**, during his research work as part of his doctoral dissertation in 1979, and in 1980, it was first published in the article Duckstein & Opricović where the acronym VIKOR was also used for the first time. This method is based on the optimization of conflicting criteria and the reference point is an ideal welcome in the observed functional space. The solution that is closest to the ideal is chosen and because of the procedure, it is called compromise (Kosijer et al., 2012).

- **Analytic Hierarchy Process (AHP)** is a very simple and therefore relatively most often implemented method for solving real problems where it is necessary to make a concrete decision in a real environment (Saaty, 1980, 2008). The name of the method describes its principles: (a) The word analyst refers to the dismantling of the problem to its building blocks; (b) The word hierarchy shows that the building blocks are arranged in sequence relative to the underlying goal; (c) The word process means that there are input and output data that are processed between these two points.

- The main advantage of this method is the ability of the decision-maker to compare alternatives. This is applied in several real-world situations (selection of contractors, selection of project managers, evaluation of project performance, hiring of new employees) where the relative importance is determined on-road scales that have structurally higher hierarchical levels (Al-Harbi, 2001; Kwak & Anbari, 2009; Saaty & Vargas, 2006; Wen-Yau, 2003). The application of AHP in the process of selecting project managers has been mentioned in several papers (Varajao & Cruz-Cunha, 2013), and it has been applied in employment (Hsiao et al., 2011). AHP consists of three main constructions (Varajao & Cruz-Cunha, 2013): (1) Problem nomination and main goal, (2) Defining a hierarchical tree of criteria on which a weight is determined for each criterion, (3) Comparison of all possible solutions.

An example of a hierarchical tree of criteria is given in Figure 2. At the second level, there are three main criteria with individual weights whose total sum should be 1000. Each of the main criteria combines its own set of sub-criteria and the sum of their weights must be 1000 (Varajao & Cruz-Cunha, 2013).
AHP is used in different situations to make certain decisions. Examples of these situations are (Saaty, 2008) as the following.

- In 2001, the method was implemented to locate the optimal new position the Adapazari, Turkish city, after the earthquake.
- In 1998, applied in the selection procedure of the best offer for the multimedia system delivery of for the British Airways fleet.
- The process was applied in the conflict between the US and China over intellectual property rights in 1995 when Chinese citizens copied music, videos and CDs. The AHP analysis, which included hierarchies benefit three, charge and danger, showed that it is better for the United States side do not permission to Chinese citizens.
- Xerox Corporation has used AHP to allocate nearly $1 billion for investigation projects.
- In 1999, it has been used in the automotive industry – Ford Motor Company, in customer satisfaction analysis to increase customer satisfaction to prioritize criteria that serve to improve customer satisfaction. Ford’s Excellence Award given to it by Expert Choice Inc. best evidence the quality of this analysis.
- In 1986, the Institute for Strategic Studies in Pretoria, government association, used the AHP to find a quality solution while analysing the conflict in South Africa and proposed actions in the interval from the liberation, of Nelson Mandela to the exemption of apartheid, to civic equality for all races. The results obtained were applied at the state level in that African country.
• In 1991, IBM used AHP to design the successful mid-range AS400 computer and therefore received the respected Malcolm Baldrige Award for Excellence.

Advantages of AHP:
• AHP structures the decision-making problem and successfully simulates the decision-making process from defining the goal, criteria and alternatives, to comparing criteria and alternatives in pairs and obtaining results, i.e. determining the priorities of all alternatives concerning the set goal.
• Decomposes the real decision-making process by decomposing the problem into a hierarchy of elements of that procedure and respects the detail that the person who decides the mental level generally does not separate the process of assessing criteria from alternatives.
• Allows control of the consistency of assessments, taking into account the totality of the problem and functional interactions of criteria and alternatives.

The following is an overview of the findings from the relevant literature.
Xing & Zhang (2006) analysed the importance of selecting a project manager and qualitatively assessed the competence of the project manager by conducting analysis using triangular Fuzzy numbers.
Rashidi et al. (2011) developed and verified a project manager selection by mathematical model established on the Fuzzy theory of ANNs and Gas. The resulting model could be an interesting replacement option for the traditional approach of project manager selection. To be precise, the information obtained by interviewing was used as input data, and the results obtained by applying this model are very close to the results of the traditional interview that was realized at the beginning of this research.
Subramanian and Ramanathan (2012) provide a very comprehensive overview of the implementation of AHP in the manufacturing industry based on their literature review.
Hadad et al. (2013) proposed model Decision-Making Support System (DMSS) for project manager selection and demonstrate its implementation. The selection criteria were based on their positive references in project management.
Varajao and Cruz-Cunha (2013) for the project manager selection procedure suggest the use of IPMA criteria of the project manager’s competence (37 competencies) as relevant criteria for the AHP model. This model can be very effective for decision-makers as it allows comparative analysis of a large number of candidates for the project manager.
Cassar and Martin (2016) used the AHP model in project manager selection in construction taking into account random and fuzzy uncertainties.
Sadatrasool et al. (2016) developed a model for project manager selection for the oil industry. The suggested model called Principle Component Analysis (PCA) is based on a multi-criteria evaluating. This method took into account all important criteria and the weight values for each criterion were obtained by interviewing an experienced group of stakeholders in projects from the oil industry. Model validation was performed by VIKOR method.

Project manager selection in Croatia
The process of selecting project managers is an insufficiently researched area at the global level and in Croatia where there is no data on any theoretical or empirical research on the mentioned topic. The cause for mentioned is probably because in Croatia the term project is traditionally associated with large infrastructure or engineering activities, so in academic circles, this issue is mainly dealt with at the faculties of civil engineering and not economics (Omazić & Baljkas, 2005).
In general, the scientific and professional literature on project management is quite modest in Croatia, where only a few scientific and professional books, textbooks and manuals have been published, for example: Omazić and Baljkas (2005), Buble (2010), Zekić (2010), Radujković et al. (2012) in which the process of selecting project managers is completely peripherally mentioned. The same situation is with the Croatian translation of the university textbook Hauc (2007) and two project management manuals, Horine (2009) and PMI (2011).

One of the scarce Croatian researchers who conduct research related to project management and the role of the project manager is Mladen Radujković - President of the Croatian Project Management Association. Unfortunately, in several of his papers, which he classified in the scientific fields of construction/economics, he only incidentally mentioned the project manager choice, for example: (i) Radujković (2000), an abbreviated description of the process of selecting project managers is given. The author especially emphasizes the need for Croatia’s participation in the international project management certification program; and (ii) Radujkovic et al. (2010) defining legal conditions for the realization of construction project management activities, further harmonization of these activities with international practice is nevertheless needed.

Ivas (2019) also mentioned the project manager selection in the context of the legal obligation to appoint a project manager in engineering activities. Namely, when is the word about project managers in Croatia, there is a certain paradox: on the one hand, in the National Classification of Professions (NN 111/98, 14/2011) the project manager is not listed as a profession, and on the other hand, following the Law on works and activities of physical planning and construction, Article 38 (NN 78/15, 118/18 and 110/19) sectoral investors are obliged to appoint a certified project manager.

There is a major disagreement in attitude related to this topic between the Ministry of Construction, which prescribes the obligation to appoint and certify project managers, and the professional chambers of civil, architectural, electrical and mechanical engineers seeking to abolish these obligations. This requires extensive analysis and goes beyond the scope of this article.

Moreover, from all the above, it is completely clear that the process of selecting project managers is an unexplored area from academic researches and practitioners’ aspects in Croatia. The results of this theoretical research can make significant scientific and applicative contributions.

**Conclusion**

The aims of this paper are: (a) to provides a useful overview of research on approaches, models, techniques, and competencies during the project manager selection process, (b) to improve understanding and effectiveness of the process of selecting project managers from academic researches and practitioners point of view (c) to make a good framework for future researchers in this under-explored area and encourage researchers to explore this topic; (d) to contribute to the development state of knowledge for this topic and practical implementation in Croatia.

The findings of the relevant literature point to the following:

- The process of selecting project managers is insufficiently researched and it has consequences on the state of knowledge for this topic and at practice, especially in Croatia.
- The project manager is a critical factor in the success of the project and its selection is an extremely complex process with long-term consequences.
Both approaches to the selection of project managers have pros and cons and neither is optimal.

The traditional approach based on the interview is simple, fast, relatively cheap, flexible, but its main drawback is that it is not suitable for a large number of candidates. The opinion of a few types of research is that this approach is ambiguous, biased, and lacking accuracy.

The modern approach, which is based on mathematical multi-criteria decision-making, in addition to the advantages it undoubtedly brings especially with a large number of candidates, also has disadvantages. Namely, in most cases, the multi-criteria models that are applied are general and do not take into account the specifics of the project and the climate. Usually, such models are complicated to apply and are rarely used.

The situation at Croatia can be described as follow: (a) State of knowledge for this topic is insufficiently researched from academic research aspect. (b) The situation in practice is complex because of the legislation inconsistencies specifically related to the certification of the project manager.

The result of this theoretical research is the proposal of a new approach that is to be a combination of the traditional and modern approach to the selection of project managers. It is a multi-stage approach, which includes the following: (i) the first stage, an initial verification of necessary/required qualifications (qualification, experience, references, certificate); (ii) the second stage, the selection procedure, the so-called selection interview, only for those candidates who have met the first stage enter; (iii) the third stage, the results of the interview would then be processed by one of the models of multicriteria decision making, e.g. AHP; and (iv) the fourth stage, based on the results of multi-criteria decision-making, a decision would be made on the selection of the best candidate.

This new approach can be more effective than the traditional or modern approach but this should be the topic of future research.

Recommendations for future researches: are as following: (i) to design research of project manager certificate validity as the key factor of project manager competency and basic criteria during project manager selection process, and (ii) to design the conceptual research model, optimizing and empirical testing of the new approach proposed by this paper.

References


40. Korres, G., Gourtsois, S., Kostouros, J. (2003), Principles of Project Organization and Management (Vol. 2), Greek Open University, School of Exact Sciences and Technology, Patra.


About the author

Marija Šiško Kuliš works at Croatian company HEP Production Ltd. as a project manager, and at the Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture in Split (FESB) as a professor. She is a Ph.D. student in the economy at Faculty of Economics, University of Rijeka. Her research interests are project management, quality, water turbine, business economy. The author can be contacted at email: marija.sisko-kulis@hep.hr
Pension Pessimism in the Young Generation: Basics or Instincts to Blame?

Erzsébet Kovács  
Corvinus University of Budapest, Institute of Mathematics and Statistical Modelling, Budapest, Hungary  
Ágnes Vaskövi  
Corvinus University of Budapest, Institute of Finance, Accounting and Business Law, Budapest, Hungary

Abstract

Background: The area of pension expectations in Hungary is barely researched. However, the importance of adequate financial literacy and self-provision is becoming obvious at the economic, the decision-making, and the individual level. Objectives: Our research is conducted to investigate state pension expectations and certain aspects of financial literacy of the young generation, and to find a behavioral explanation for their pessimistic attitude. Methods/Approach: Using a 14-question questionnaire, we collected answers from Hungarian financially educated, young people. Two hypotheses were investigated by the Principal Component Analysis (PCA). Besides, a comparative analysis was conducted to connect the survey results with the ten instincts published by Hans Rosling in his book ‘Factfulness’. Results: The outcomes are in harmony with prior expectations, i.e. i) students in finance major are aware of the connection between a longer working period and a higher retirement income; and ii) despite the unisex pension scheme there are gender differences in the expected pension age. In the comparative analysis with ‘Factfulness’, we identified five instincts that lie behind the general pessimism of respondents. Conclusions: State pension expectations of the Hungarian young generation are overly pessimistic, the same attitude being found in international literature, as well. Pessimistic expectations can be explained using some of the ten instincts by Rosling.

Keywords: retirement income, social security expectations, financial literacy  
JEL classification: G4, G510, G530  
Paper type: Research paper

Received: Jan 31, 2020  
Accepted: Jul 06, 2020

DOI: 10.2478/bsrj-2020-0019

Introduction

Pension is always a hot topic. Politicians, economists, demographers, and other theoretical and professional experts study it from several aspects, and this is one of the
most important everyday-life questions for individuals, as well. Considering longevity risk, people must be aware of the financial burden deriving from prolonged retirement years and be prepared to turn to active self-provision. Financial literacy is strongly connected to the willingness to plan for retirement, and this has already been recognized by the governments of several countries. Governmental strategies are formed to increase financial literacy, an intention that may be heralded but which should also be funded by examining the knowledge, as well as the expectations, of the different age groups.

The main purpose of this study is to explore the pension expectations of the Hungarian young generation and to find the behavioral aspects behind their attitude using Hans Rosling’s book ‘Factfulness’. The basic question of ‘Factfulness’ is why people see the world as much worse than it is, a phenomenon that he calls ‘overdramatic worldview’. This paper investigates a similar question: why young people determine social security benefits after retirement to be much worse than they might actually be.

Many international studies investigate pension expectations in connection with the rising statutory retirement age (Coppola & Wilke, 2014), the replacement rates (de Bresser & van Soest, 2015) or the well-being in retirement ages (Lusardi & Mitchell, 2011). We find examples of expectation surveys in different countries (Greenwald et al., 2017; Sekita, 2011) or different age groups of individuals (Lusardi & Olivia, 2014). Nevertheless, pension expectations in Hungary is a barely researched topic, thus in this aspect, our research is novel examining the Hungarian young generation’s state pension expectations and connecting them to certain human biases reported by Rosling.

The structure of our paper is the following. In the next section, we briefly present the characteristics of the Hungarian pension system to form the context for the expectations analysis. Then, after giving a short literature review, we describe our survey data and methodology, and we show our results including their connections with Rosling’s ten human instincts. Before concluding our research, we present a discussion comparing our results with existing work and we list our contributions to the literature and practice. Finally, in conclusion, implications and limitations are described.

**Hungarian Pension System**

The Hungarian pension system is currently a statutory, one-pillar, pay-as-you-go scheme where all employees are covered and the pension is calculated based on earnings and working years.

The mandatory second pillar was abolished in 2010 when most of the savings in mandatory private pension funds were redirected back to the state pension system. Third and fourth pillars of the pension system are voluntary with individual- and employer-financed saving forms, which are supported by the state through tax incentives. Pillars of the Hungarian pension system are shown in Table 1.

The amount of starting a pension is determined by the number of years worked and the salary level of the last active years. According to the Organisation for Economic Co-operation and Development pension study (OECD, 2019), in 2018 the net replacement rate was 84.3% for men and 78.4% for women. The corresponding figure is available for 2014 in the OECD database when it was 89.6% uniform. We are certainly witnessing a slight decline in the rate, but even so, Hungary remains well above the OECD average of men 58.6% and women 57.6%.
Table 1
Pillars of the Hungarian Pension System

<table>
<thead>
<tr>
<th>Pillar</th>
<th>Mandatory</th>
<th>Finance</th>
<th>Attributes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pillar I</td>
<td>yes</td>
<td>pay-as-you-go (DB)</td>
<td>statutory</td>
</tr>
<tr>
<td>Pillar II</td>
<td>-</td>
<td>-</td>
<td>abolished in 2010 and funds transferred to the state fund, approximately 50,000 individual accounts remained</td>
</tr>
<tr>
<td>Pillar III</td>
<td>no</td>
<td>individual contributions</td>
<td>voluntary pension funds with individual accounts</td>
</tr>
<tr>
<td>Pillar IV</td>
<td>no</td>
<td>individual contributions</td>
<td>other retirement saving schemes with tax subsidies</td>
</tr>
</tbody>
</table>

Source: Authors’ work

The official retirement age was increased gradually from 62 years to 65 by 2022. Thus, following the European Union’s regulation on the unisex pension system, Hungary also has a unisex pension system with one exception, i.e. women with a 40-years eligibility period can retire even before this increased official retirement age (this program is called 'Women40'). This option needs even higher financial literacy and risk awareness by women because, besides their higher life expectancy, the 'Women40' program may prolong their retirement period even further. On the other hand, studies show that raising the retirement age does not provide a comprehensive solution to the problems of the pay-as-you-go pension system, inter alia Bajkó et al. (2015) proves with their demographic forecast and pension model that between 2026 and 2034 the state pension fund will accumulate a sound deficit, which can reach up to 8% of the pension fund’s revenues. However, Németh et al. (2019) evaluate the raise of retirement age as a fundamental solution for pension schemes answering demographic and labour market developments in the 21st century.

Another issue is the impact of an ageing society on the pension system. In their study, Májer and Kovács (2011) emphasize that the defined benefit (DB) pension system in Hungary is particularly sensitive to longevity risk, as in this system the amount of pension is determined not by the amount of contributions but primarily by the number of years worked.

Therefore, several warning signals call attention to the structural problems of the current pension system in Hungary. In our study, we rather approach this issue from the individuals’ perspective. In the long run, the one-pillar state pension system does not necessarily guarantee a decent living standard for retirement years, therefore, as described in Vaskövi’s (2018) article, active years’ pension awareness is an essential input for financial stability in the long run. Thus, it is highly important to understand the expectations of the young generation regarding the state pension system and to see how deeply they are aware of the longevity risk.

**Literature Review**

In most developed countries, it is an increasing need for individuals to understand the importance of self-provision, which is strongly connected to financial literacy. Lusardi (2015) enhances the high responsibility of the younger generation because their financial decisions could affect on the very long term. Saving and investing are the basis of financial security not only for specific life stages (childbirth, unemployment, long-term illness, etc.) but also for the whole retirement period. In Hungary, the pay-
as-you-go (defined benefit, DB) pension scheme seemingly takes over this ‘save and invest’ responsibility from the individuals.

Although, in Hungary, only a few studies are investigating pension expectations. Czibik et al. (2007) surveyed retirement saving awareness, asking 1000 Hungarian adults between 18 and 59 years how they prepare for their retirement period. The survey found that one-third of the respondents do not prepare at all. Regarding their knowledge of the pension system, most respondents lacked information, e.g. on the applicable retirement age or pension contributions. Czibik et al. (2007) also found evidence of higher pension literacy among respondents with higher education and older age. This study rather investigated the retirement preparations knowledge and not the expectations.

Simonovits (2015) built a model to examine how much the lack of pension knowledge affects decisions on retiring age. He found that without sufficient knowledge such decision-making is suboptimal. He also drew attention to the complexity of the Hungarian pension system, which could be an argument behind the insufficient knowledge and the low pension literacy of the active-age population.

Ágoston et al. (2016) surveyed 59 practitioners of the actuarial and economics professions, asking their adaptation to self-provision necessity. The survey examined pension knowledge as well as certain aspects of retirement expectations of a small group of highly qualified professionals and found that most of them had irrational expectations and even superficial knowledge of pension facts and possibilities. Although the data were neither representative nor a large sample, the findings revealed pessimistic pension expectations.

The literature of financial literacy and pension expectations is comprehensive in the United States. There are numerous researches conducted, inter alia the Retirement Confidence Survey (RCS), which has been taken annually since 1991 by the Employee Benefit Research Institute (EBRI) and the independent research firm, Greenwald & Associates. This survey investigates the knowledge and attitudes of active and retired individuals regarding retirement and preparations for retirement. Based on the RCS of 2017, Greenwald et al. (2017) found that most of the active respondents ‘lack retirement confidence and feel stressed about retirement preparations’.

Lusardi et al. (2011) in the National Bureau of Economic Research (USA) have conducted numerous researches in financial literacy, financial education and related topics. In 2011, they reported about a survey on planning and financial literacy of Americans where they found evidence of a lack of financial literacy among minorities, the older generation or less educated people (Lusardi et al., 2011).

Prados et al. (2019) explained in their working paper that most Americans have significant biases and irrational expectations as to future retirement benefits. These irrational thoughts can lead again to suboptimal saving plans and reduce the overall well-being of pension years.

We also found relevant European studies of pension literacy and expectations. Barrett et al. (2015) made a representative survey in the older active-age population in Ireland. In line with other studies, they found that the vast majority of respondents were not aware of the amount of their expected pension, and especially women and less educated people lacked the essential knowledge. Coppola et al. (2014) examined a special German case, i.e. they studied the subjective retirement expectations concerning increases of the statutory retirement age. Sekita’s (2011) study presented severe financial illiteracy in Japan. In the Netherlands, de Bresser et al. (2015) dealt with the interconnection of financial literacy and subjective expectations as to salary replacement rates.
We could enlarge the list of related European and American literature, however, in Hungary, the financial literacy and subjective pension expectations are a relatively new research agenda.

**Methodology**

In our study, we examined survey data on university students’ expectations as to their future retirement income and social security benefits as a major source of this income in Hungary. We defined the group of respondents to be highly educated and fairly far from retirement to have a sample with relatively good financial literacy but also a long uncertain period before retirement.

Our survey consists of 14 questions: five on demographic data and nine on social security benefits. The nine are grouped as follows:

i. expectations as to future retirement benefits (four questions) - we asked if students expect to get social security benefits, what level of trust they have that the government would provide these benefits, and what is their attitude to the Hungarian pension system,

ii. generosity of benefits (two questions) - these two questions are examining what proportion of total future retirement income would come from the state pension system, and the estimated salary replacement rate (it is the proportion of social security benefits related to the worker’s salary near the end of his or her working career),

iii. receipt of social security benefits and retirement age (three questions) - we also inquired if students plan to leave Hungary for their working years and which are the destination countries, and we formed two questions about retirement age and the earliest possible age at which retirement benefits might be received.

We gathered 320 responses out of which we excluded 70 because of any invalid data, thus in our final dataset there are 250 records with the demographic data distributions as Table 2 shows.

<table>
<thead>
<tr>
<th>Table 2</th>
<th>Demographic Data Distribution of Survey Data</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Gender</strong></td>
<td>Male</td>
</tr>
<tr>
<td></td>
<td>Female</td>
</tr>
<tr>
<td><strong>Age</strong></td>
<td>Between 19 and 24 years</td>
</tr>
<tr>
<td></td>
<td>Between 25 and 42 years</td>
</tr>
<tr>
<td><strong>Present major</strong></td>
<td>University – finances</td>
</tr>
<tr>
<td></td>
<td>University – economics (not fin)</td>
</tr>
<tr>
<td></td>
<td>Other university</td>
</tr>
<tr>
<td><strong>Region of origin</strong></td>
<td>Budapest and Pest county</td>
</tr>
<tr>
<td></td>
<td>Other counties</td>
</tr>
<tr>
<td><strong>Residence</strong></td>
<td>Budapest and Pest county</td>
</tr>
<tr>
<td></td>
<td>Other counties</td>
</tr>
</tbody>
</table>

Source: Authors’ work

We also stated two hypotheses; the first connected to financial literacy and the second concerning gender differences in the pension scheme. We used factor analysis, which is a multidimensional statistical method to compress information of the original variables, thus to reduce the dimension of the analysis. From the numerous methods of factor analysis, we applied Principal Component Analysis (PCA) for factor extraction, where the uncorrelated linear combination of variables is calculated based on eigenvalue-eigenvector decomposition of the correlation matrix of the
original variables included in the model. Factors driven from PCA were used to test our two hypotheses.

We made a comparative analysis using our survey results and the ten biases from Rosling’s ‘Factfulness’ in order to find the behavioral aspects lying behind the pessimistic attitude of most respondents.

Results

Based on data of the Organisation for Economic Co-operation and Development (OECD), slightly more than 20% of the total Hungarian population received retirement benefits from the state pension scheme, which amount was an average approximately 80% of the net average wage in 2018. This net pension replacement rate is one of the highest among OECD countries. The increase of population receiving social security benefits and the high salary replacement rate are warning signals of the sustainability of the Hungarian pension system, however, the high replacement rate might be good news for individuals. Most of the population might not be aware of the exact pension figures; however, the survey outcome shows that people’s expectations are overly pessimistic.

Expectations as to future retirement benefits

We formed four questions in this section: (i) how likely it is to receive government-provided social security retirement benefits, (ii) is this likelihood different for their peers, (iii) what reasons lie behind their negative attitude – if any, and (iv) the level of trust they have that the government will provide future promised social security retirement benefits? In general, young people have negative expectations as to whether they will receive a state pension upon reaching the retirement age. Concerning the first question, half of the respondents said they had less than a 50% chance of receiving a state pension, while only 18% said the chance was above 80%. The proportion of those who are absolutely certain that they will not receive a state pension is 4% and on the other hand, those who are absolutely (100%) sure that they will receive it is also 4%. Concerning the second question, 72.8% of the respondents expressed their negative expectations as to their state pension. Their answers to the third question are summarized in Table 3.

Table 3
Different Reasons for Negative Attitude to Social Security Benefits

<table>
<thead>
<tr>
<th>Why do you have certain views on social security benefits?</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>The government has frequently changed social security benefits</td>
<td>7.7%</td>
</tr>
<tr>
<td>Hungary’s future is uncertain</td>
<td>12.1%</td>
</tr>
<tr>
<td>I don’t trust the government</td>
<td>13.7%</td>
</tr>
<tr>
<td>I plan to leave Hungary thus I might not get Hungarian social security benefits</td>
<td>6.0%</td>
</tr>
<tr>
<td>The increasing percentage of the population that is retired will cause a reduction in the generosity of social security benefits</td>
<td>55.5%</td>
</tr>
<tr>
<td>Others</td>
<td>5.0%</td>
</tr>
</tbody>
</table>

Source: Authors’ work

Our young respondents are aware of the longevity risk and the necessary pension system changes. This reason most defines (55.5%) their negative attitude.
Finally, on the fourth question, the level of trust that the government will provide future promised social security retirement benefits is overly low. 20% of respondents say that they do not trust in government at all, and 66% have less than 50% trust. Only 1.6% fully trust in the social security payments of the government.

**Generosity of benefits**

The two questions of this section were: (i) what percentage will be the state pension of their total future retirement income, (ii) how much will be the future salary replacement rate?

Currently, the salary replacement rate in Hungary depends on the years worked and the average net salary. If a person has 40 years of working period s/he receives 80% of last average net wages if the working period is 50 years the rate increases to 90% (84.3% of pre-retirement earnings were paid for men pensioners and 78.4% for women in 2018, (OECD, 2019)). Despite this, 58.4% of respondents said they would receive less than 50% of the salary as social security benefits and only 3.6% estimated the salary replacement rate at 80% or higher. Ágoston et al. (2016) found a similar result in their study, adding that their respondents earning higher average income considered an even lower replacement rate.

The state pension proportion of total retirement income was underestimated, with 61.6% of students saying it would be lower than 50% and only 1.2% expecting to get more than 90% of total income from the social security funds.

**Receipt of social security benefits (age-related questions)**

Here we asked three questions: (i) the home country where they want to spend the working period, (ii) what will be the earliest age when they potentially retire, (iii) what will be the age when they retire in practice?

Concerning the first question, only 46.8% responded 100% sure that they want to stay in Hungary. We also asked them about their expected retirement age, and 54.4% expect to retire later than 66 years old and only 16.8% expect early retirement (before 65 years).

Respondents also expressed their expectations as to the earliest age at which they would receive social security retirement benefits. More than three-quarters (77.6%) said this earliest age would be at least 65 years, and only 10% expected this age somewhat before 62 years.

This expectation of extended working life makes the results of Cebulla et. al (2019) even more remarkable. They found that age management is a European challenge to regulate and motivate companies to form acceptable working conditions for elder employees in all countries.

**Factor analysis**

To test our null-hypothesis, a linear factor model was created with Principal Component Analysis. With the development of uncorrelated components, we sought to find out the relationship between the three different groups of social security questions. The best-fitting model includes six variables equally distributed among the three types of pension expectations variable groups: two of expectations, two of generosity and the other two of receipt (age). In this factor model, two orthogonal, uncorrelated components with eigenvalue higher than 1 were extracted from the six original variables, with the extraction of 72.247% of information as a ratio of the original variances. The suitability of our data for PCA is shown in Table 4.
Table 4
Measures of Data Adequacy for PCA

<table>
<thead>
<tr>
<th>KMO and Bartlett’s Test</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Kaiser-Meyer-Olkin Measure of Sampling Adequacy</td>
<td>0.762</td>
</tr>
<tr>
<td>Bartlett’s Test of Sphericity</td>
<td></td>
</tr>
<tr>
<td>Approx. Chi-Square</td>
<td>592.789</td>
</tr>
<tr>
<td>df</td>
<td>15</td>
</tr>
<tr>
<td>Sig.</td>
<td>0.000</td>
</tr>
</tbody>
</table>

Source: Authors’ work

KMO value is 0.762, meaning the data is suitable for Principal Component Analysis. The correlations between the original variables and the two components are shown in Table 5 (the empty cells represent very weak correlations).

Table 5
Rotated Component Matrix of Two-factor Solution

<table>
<thead>
<tr>
<th>Component</th>
<th>Factor 1 (Expectations &amp; generosity)</th>
<th>Factor 2 (Age)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Expectations</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Expectations to get social security benefits</td>
<td>0.838</td>
<td></td>
</tr>
<tr>
<td>Level of trust that the government would provide social security benefits</td>
<td>0.829</td>
<td></td>
</tr>
<tr>
<td>Generosity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The proportion of total future retirement income coming from the state pension system</td>
<td>0.902</td>
<td></td>
</tr>
<tr>
<td>Salary replacement rate</td>
<td>0.832</td>
<td></td>
</tr>
<tr>
<td>Receipt (age)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The earliest age at which the pension system allows to collect social security retirement benefits</td>
<td></td>
<td>0.829</td>
</tr>
<tr>
<td>Expected retirement age</td>
<td></td>
<td>0.842</td>
</tr>
</tbody>
</table>

Source: Authors’ work

Hypothesis testing
As introduced in the ‘Data and Methodology’ section, we formed two hypotheses on the students’ pension expectations: (i) H1: respondents with finance major have higher pension literacy than other students, and, and (ii) H2: pension expectations do not depend on gender.

Considering H1 we found that students in finance major are aware of the interdependencies of a longer working period and higher retirement benefits (mean of receipt factor score is 0.124 by finance major and -0.058 by respondents in other majors), however, we did not find a significant difference in expectations between the groups of majors (independent t-test value for Factor 1 (Expectations & Generosity) is -0.605 with p=0.546, and t-test value for Factor 2 (Age) is 1.368 with 0.173 p-value, which is not significant on any typical significance level).

Considering H2 we found statistical evidence that male respondents count on higher retirement age (mean of age factor score is 0.176 by male and -0.248 by female respondents). Despite the unisex pension scheme, the reason for later retirement expectations for men might be the awareness of the ‘Women40’ program or the former gender-defined system. Figure 1 shows gender differences between two factors. Factor 2 (Age) is significantly different on male and female respondents on
any significance levels (t-test value is 3.373 with a p-value of 0.001). Factor 1 is not significantly different according to gender (t-test value=0.517 and p=0.605).

Our results are in line with the findings of Bahovec et. al (2017) who also emphasized the statistically significant impact of gender and financial literacy on individual financial performance in their study.

*Figure 1*
Differences According to Gender Expectations

Source: Authors’ illustration

**Ten Instincts by Hans Rosling and their Connection to Pension Expectations**

People might be optimistic in other fields of life because overconfidence and optimism are socially valued personal traits as stated by Forbes (2009). Based on this overconfidence people tend to take too much risk, for example in their personal financial decisions (e.g. taking consumer debts or car leasing). However, in several other questions about the world or even about pension issues we are rather pessimistic.

Based on our research results we see that pension expectations do not depend on gender, nor education, age or profession. Individuals from different countries with mainly diverse pension schemes have overall pessimistic expectations as to their state pension and future social security benefits. Several possible reasons could lie behind this, thus in this section, we want to connect Hans Rosling’s ten instincts with the negative pension expectations to present one potential explanation.

‘Factfulness’ was first published in 2018, crowning Rosling’s life-long battle against misconceptions, biases and stereotypes which lead people to a fairly negative worldview. He worked on his book in collaboration with his son Ola Rosling and his daughter-in-law Anna Rosling Rönnlund. Their book is based on Rosling’s questionnaire with 13 fact questions that he used in most of his presentations held all over the world for decades, and finally in 2017 launched in 14 countries as a representative survey to test 12,000 people. He called this survey the Gapminder Test. Countries that took part were Australia, Belgium, Canada, Finland, France, Germany, Hungary, Japan, Norway, South Korea, Spain, Sweden, the United Kingdom, and the USA.
Why do students, workers from different countries, judge their future retirement and social security benefits in a highly pessimistic manner? In addition, why does Rosling’s different audience (be they politicians, corporate executives, green activists, or whomever) answer his 13 questions based on a negative worldview? The answer might be similar and strongly connected to ten dramatic biases that lead people to wrong perceptions about the world. These biases are called instincts by Rosling.

As follows, we grouped Rosling’s instincts in three groups (hot, warm, and cold) based on their connection to our pension expectations research results (Table 6).

Table 6
Grouping of Instincts from ‘Factfulness’

<table>
<thead>
<tr>
<th>Connected to pension expectations</th>
<th>Hot (Yes)</th>
<th>Warm (Possible)</th>
<th>Cold (No)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gap Instinct</td>
<td>Size Instinct</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Negativity Instinct</td>
<td>Blame Instinct</td>
<td>Destiny Instinct</td>
<td></td>
</tr>
<tr>
<td>Generalization Instinct</td>
<td>Single Perspective Instinct</td>
<td>Fear Instinct</td>
<td>Urgency Instinct</td>
</tr>
</tbody>
</table>

Source: Authors’ work

“Hot” instincts, that are firmly behind pessimistic pension expectations

The Gap Instinct. Rosling calls this bias one of the most dangerous misconceptions. People following the Gap Instinct divide everything into two – and only two – distinct groups with a gap in between, e.g. good and bad, rich and poor, my country and all the others, or even black and white. With this misbelief, people lose the ‘grey zone’, i.e. all cases between the low and high extremities.

Following this instinct people tend to say ‘I will have’ or ‘I will not have’ a state pension. In our study, 72.8% of respondents expressed their negative expectations as to their state pension, however in the Hungarian pension scheme all employees are covered by a state pension. This finding is in line with Rosling’s that most people’s opinions are a rather unsubstantial feeling without real fundamentals to account for this. Rosling warns us that the media is the best friend of this instinct (moreover media strengthens most of our ten misleading instincts), which could be easily understood because our young respondents are far from retirement and therefore they do not have their own, firsthand experience about pension and its related issues. Young people form their opinion on pension following secondhand experiences communicated by the mass media, which is often misleading.

The Negativity Instinct. Rosling defines the second human bias as ‘negativity instinct’, where people are prone ‘to notice the bad more than the good’ (Rosling, 2018, p.48). Three main reasons lie behind this: our memory distorts past events; media and activists report mainly about negative news, and we tend to feel remorse by recognizing improvement while things are bad (e.g. any people live in extreme poverty). Related to this we found that only 9.2% of respondents believe the replacement rate would be above 70% of the net average wage, which is fairly low comparing to the currently used 78-85% rates which could be based on negativity instinct. The vast majority of pension-related news warns people that an ageing society jeopardizes the sustainability of the pension scheme in Hungary, which leads people to be overly pessimistic.

The Generalization Instinct. Rosling says ‘everyone automatically categorizes and generalizes all the time – unconsciously’ (Rosling, 2018, p.146). Categories are necessary for humans to provide a stable framework for our thoughts. However, this
might distort our worldview by making us group together rather heterogeneous things. This instinct is also strongly supported by the media forming quick and easy-to-understand categories, such as middle class, poor and rich, etc. The generalization instinct is firmly connected to the gap instinct while the latter divides the world into two opposing parts where one part thinks the other part is homogenous. As per pension expectations, our respondents tend to generalize the retirement benefits and the generosity of the state pension system. This generalization could cause a homogenous pessimistic attitude across countries, gender, and age.

“Warm instincts”, that are partially behind pessimistic pension expectations

The Straight Line Instinct. The third ‘mega misconception’ leads to the straight line instinct that is defined in ‘Factfulness’ as ‘the world population is just increasing and increasing’ (Rosling, 2018, p.77). Rosling presents the United Nations’ forecast for human population growth, which predicts a slowing increase and a flattening curve of the world population. According to this UN prediction, the total population will grow to 11 billion by 2075 out of which 3 billion people will be above 60 years. In our research, the straight line instinct might be a key player of the misconception that an ageing population is an ‘endless process’ (as it was defined as the main reason of the negative attitude to social security benefits shown in Table 3). Life expectancy constantly increased in the last 20 years; however, the growth has already started to slow down in the last two years. There are countries where life expectancy is still rising steeply but their basis is significantly lower than in most developed countries. Today data show life expectancy and the number of retired population is not growing as a straight line.

The Blame Instinct. The blame instinct goes hand in hand with a single perspective instinct. This is also a potential mean to simplify complicated situations and questions. ‘The blame instinct makes us exaggerate the importance of individuals or particular groups’ (Rosling, 2018, p.207). Regarding pension expectations, we could not identify one single factor to blame. However, most of our respondents (55.5%) ‘blame’ the ageing society for the problems of the pension system, saying that the increasing percentage of the population that is retired would cause a reduction in the generosity of social security benefits.

“Cold instincts”, considered as not lying behind pessimistic pension expectations

The Size Instinct. The size instinct comes from that aspect of human nature which makes us misjudge the size of things. People tend to misjudge situations where they do not have enough information. The media could be strengthening this instinct by constantly presenting extreme events, thus making us systematically underestimate progress and overestimate negative trends. In our research, size instinct could be relatively difficult to identify. General pessimism in pension expectations might not come from getting things out of proportion but rather from a negative media communication.

The Destiny Instinct. Rosling defines the destiny instinct as ‘the idea that innate characteristics determine the destinies of people, countries, religions, or culture’ (Rosling, 2018, p.167). With this instinct, people see some aspects of the world unchanging and unchangeable, and they are unwilling to refresh their knowledge about transformations or improvements. The destiny instinct might have no role in our expectation research, taking into consideration that the main reasons for the negative
attitude to the state pension system were the constant changes and the uncertainty deriving from them.

**The Single Perspective Instinct.** Rosling calls the human preference for simple answers and solutions the single perspective instinct. With this instinct, we can explain even difficult problems with one single idea. This is a very dangerous attitude ‘being always in favour or always against any particular idea’ (Rosling, 2018, p.186) because it could make people blind and deaf to other opinions or facts. Rosling found two main reasons for this instinct: political ideology, and professional.

People tend to find simple answers to even complex questions such as the future retirement benefits. In our research, we did not find the single perspective instinct, the reasons behind negative expectations being various, as stated in Table 3.

**The Fear Instinct.** This instinct helped humans survive under extreme circumstances so it has evolutionary importance. However, in our safe world, the fear instinct could be harmful if it distorts our worldview. People still have fears and if these fears are common for many people it could make us all cooperate, to achieve the best progress. Common fears, for example about an unhealthy environment, gave birth to environmental protection. Therefore, ‘fear can be useful, but only if it is directed to the right things’ (Rosling, 2018, p.122). Fear is a special instinct where we cannot identify connections to financial literacy or pension expectations.

**The Urgency Instinct.** The last instinct in ‘Factfulness’ is the urgency instinct that ‘makes us want to take immediate action in the face of a perceived imminent danger’ (Rosling, 2018, p.227). The urgency instinct is strongly connected to the fear instinct. However, in this research, we did not survey the students’ preferred solutions to lower the financial uncertainty of their retirement period, but the fear or urgency instincts might get a role in their further self-provision actions. Rosling explains that the urgency instinct influences people’s short-term decisions, however in the long run they do not seem to have the same instinct. Rosling states that this is the reason why so few people save enough money for their retirement. This particular question could be the most prominent on the agenda of any future research.

**Discussion**

In our research, we investigated the state pension expectations involving Hungarian students in an international survey in January 2019. Similar research was conducted in the USA, Canada and Ireland by Turner et al. (2019) before our survey.

Despite the similarities between our research and Turner’s, comparison of the results should be very cautious. While survey countries are different concerning their pension schemes and their future and past reforms, all countries’ respondents are overly pessimistic regarding the future social retirement benefits. All countries’ survey data indicate that underestimating the future social retirement income depends on neither the gender nor the financial literacy of the respondents. In Hungary, students are equally as pessimistic as workers in Ireland, the USA or Canada are. Alessie et al. (2011) also reported from the Netherlands that employees expect lower replacement rates and increasing uncertainty.

Since the four surveyed countries are highly heterogenic in respect of – inter alia – their pension scheme, the respondents’ age and their social situation, in this paper we want to investigate also the background of this rather general pessimistic attitude. We formed the title question of this paper: are there fundamentals behind this or are the answers based on simple human biases? Our survey contained some questions about motivation (what lies behind the respondent’s answer) but since the pension schemes in the investigated countries are fairly different, we did not find sound fundamentals for the negative expectation as to state pension conditions. Thus, in this paper we
concentrated on the possible behavioural explanations and called on Hans Rosling’s famous book, ‘Factfulness’ to help us understand these pessimistic retirement expectations.

Conclusion

In our study, we explored survey data collected among Hungarian university students about their future state pension expectations. We found that most of the respondents are characterized by a general pessimism, and despite the unisex pension scheme, male participants expect a later retirement age. We could also identify that students with finance major might have more accurate information about the proportionality of higher retirement age and higher potential social security benefits.

We connected the general pessimism of our survey respondents with Hans Rosling’s inspiring book ‘Factfulness’. We identified Rosling’s ten instincts behind the negative attitude and found that gap, negativity, and generalization instincts are the very basis of people judging state pension systems.

Comparing our results to the international literature, we also found that the subjective pension expectations could distort retirement preparations, thus pension knowledge and financial literacy are to be improved significantly. The pessimistic attitude of respondents does not depend on the actual state of pension systems, on whether their financing is sufficient in the long term. In Canada and Ireland, where the pension systems are considered rather more stable than in the USA or Hungary, expectations are also pessimistic. Turner et al. (2019) found that these perceptions might change slightly when respondents get older. Concerning the Hungarian literature, we found only a few studies about pension expectations. The small survey conducted by Ágoston et al. (2016) also came to similar results: retirement expectations are pessimistic and pension knowledge of their respondents is limited. Czibik and Medgyesi (2007) rather concentrated on retirement saving awareness but they also found a lack of fundamental knowledge. Simonovits (2015) drew attention to the complexity of the Hungarian pension system that might also serve as a background for irrational expectations.

Our study revealed general pessimism among Hungarian economic university students as to the social security benefits. Rosling’s ‘Factfulness’, used in our comparative analysis, also highlights that basic knowledge could erase the ‘overdramatic worldview’, i.e. the general pessimism. The Hungarian government already accepted an overall strategic plan for improving financial literacy in 2017, which includes an operative plan for improving pension literacy of individuals. The policy should take into consideration that even those highly educated students with economic studies are regarding the state pension with subjective expectations; therefore it would be highly important to improve pension knowledge from high school ages.

The following limitation should be taken into account regarding the presented research result, stemming from the fact that we conducted our research on a special sample that is not representative. To accumulate more general implications on pension expectations we should analyze both a wider and bigger sample. For a further research agenda, a comparative study involving economic students in the Visegrád Four, Central-European countries (Slovakia, Czech Republic and Poland, alongside Hungary) should be conducted.

Acknowledgements

This publication/research has been supported by the European Union and Hungary and co-financed by the European Social Fund through the project EFOP-3.6.2-16-2017-
00017, titled “Sustainable, intelligent, and inclusive regional and city models”. Editor-in-Chief Professor Mirjana Pejić Bach and the anonymous reviewers provided valuable comments, which significantly raised the quality of our paper.

References

About the authors

Erzsébet Kovács, PhD is head of the Department of Operational Research and Actuarial Sciences at Corvinus University of Budapest. Her main fields of research are applications of multivariate statistical methods in international comparison of insurance markets, comparison and modelling pension systems, mortality projections, risk analysis in student loan system, and statistical analysis of the period of economic transition in Central-Eastern Europe. The author can be contacted at erzsebet.kovacs@uni-corvinus.hu

Ágnes Vaskövi, MSc is a PhD candidate at Corvinus University of Budapest, and an assistant professor of the Institute of Finance, Accounting and Business Law. She earned her master’s degree in Economics from Corvinus University of Budapest, specializing in financial investment analysis. She gained professional experience in fields of project financing, venture capital and real estate investments. Currently, she is a lecturer at the Department of Finance, teaching Finance, Corporate Finance, and Multivariate Data Analysis. Her main research agenda contains topics of behavioral finance, financial literacy, long-term savings, and pension. Her email address is agnes.vaskovi@uni-corvinus.hu
A System Dynamics Approach to Decision-making Tools in Farm Tourism Development

Maja Žibert
Faculty of Agriculture and Life Sciences, University of Maribor, Slovenia
Črtomir Rozman
Faculty of Agriculture and Life Sciences, University of Maribor, Slovenia
Andrej Škraba
Faculty of Organizational Sciences, University of Maribor, Slovenia
Boris Prevolšek
Faculty of Tourism, University of Maribor, Slovenia

Abstract

Background: Besides visiting the main tourist attractions in Slovenia, many tourists want to spend their free time in the countryside as well, but the number of farming establishments in Slovenia diminished distinctly in the last years. Objectives: This paper aims to develop a system dynamics model, with the goal to analyse dynamics of the diversification of agricultural holdings into farm tourism activities in Slovenia. Methods/Approach: A system dynamics methodology was chosen to model the diversification in farm tourism. First, we present a basic concept of a system dynamics model with a causal loop diagram. Further, a system dynamics model with different scenarios is presented. Results: The main feedback loops were identified, and the simulation model was used to analyse different simulation scenarios of the transition of farming establishments into farm tourism facilities. Conclusions: The model provides the answers to the strategic questions about the dynamics of transfer into tourist farms, using several simulation scenarios. The transition mainly relies on subsidies, promotion of diversification and the growth of rural tourism, which provides a relevant direction for the development of future incentives.

Keywords: farm tourism, rural tourism, modelling, system dynamics, causal loop diagram, simulation
JEL classification: Q13
Paper type: Case Study
Received: Jan 31, 2020
Accepted: Jul 6, 2020

Introduction

Rural tourism has grown in many parts of the world in the last few decades, including Slovenia. In addition, rural tourism allows the development of the countryside, which is
increasingly important in the era of growing urbanization. Countries are urgently aiming to find the ways on how to incite economic activity in the rural areas, and rural tourism is gaining popularity as one of the most important tools in that endeavour. However, various factors impacts the transitioning of rural areas to the tourism attractive destinations. Bontkes & van Keulen (2003) defined different factors that affect mainly the socio-economic conditions of rural areas. Through his research, Sharpley (2002) emphasized that low income, relatively low demand, and a lack of skills to develop activities affect the development of rural tourism. Studies showed that tourism as a non-agricultural activity on the farm does not represent only economic benefits. Non-economic benefits are also important (Tew & Barbieri, 2012). Ollenburg and Buckley, (2007), Barbieri, (2010), Jaafar et al. (2015), Cuncha et al. (2018) and Park et al. (2015) address the importance of marketing opportunities, family connections, and personal pursuits as the most common non-economic benefits of farm tourism.

Many scientists have solved problems related to the development of agriculture and tourism by using different models of system dynamics. Sedarati (2015) proves with his study that the use of the method of system dynamics in tourism is very widespread. Through the research, he found as much as 369 articles that are connected with applying the system dynamics in tourism indirectly or even directly. Several examples will be described. According to Johnson et al. (2008), a model for understanding the ecological, agronomic economic and social dimensions of rural regions has been developed. In their article, Lazanski & Kljajić (2006) described important contributions in the development of models of system dynamics that are bound with the field of tourism. Jakulin (2016) discusses the usage of system dynamics in the area of tourism.

The goal of our work is to boost the development of rural areas into rural tourism destinations by using system dynamics modelling, with the focus to the diversification, where agricultural holding extend its basic activities. In addition to the studies mentioned earlier, numerous of researchers (e.g. Bastan et al., 2018; Blumberga et al., 2018; Rozman et al., 2013) already used such types of dynamics, and in our work we extend their previous research.

The subject of the research are the main factors that influence the diversification of the agricultural holdings into tourism as the non-agricultural activity. This paper aims to analyze, utilizing systems system dynamics, the main variables and their causal relationships in the system structure, presenting the diversification of the agricultural holding into farm tourism. The case study of Slovenia has been used in order to explore different scenarios for farm tourism development.

**Background**

Farm tourism is not a new phenomenon (Busby & Rendle, 2000). It is a form of countryside tourism which dates back a century in some destinations (Dernoi, 1983). The developmental trends show that more supplementary activities are registered within farming establishments every year. Their common denominator is tourism. It is the consequence of the increasing number of tourists, i.e. lodgings in the country. In 2018, Slovenia recorded 5.93 millions of tourists’ arrivals and 15.96 millions of lodgings of the tourists. A part of them resides in tourist farms too. A rich history of the development of tourism in the countryside is recorded in Germany (Oppermann, 1996) and Austria. State policies are positively oriented towards the development of tourist facilties in the countryside with subsidies and programs of development also in Italy (Giaccio et al., 2018) and France (Bel et al., 2015).
The number of farms in Slovenia is decreasing. Figure 1 presents the number of Farms in Slovenia from 2003 to 2016 (SORs, 2020). The important factor that influences this trend is farm income, which can be improved by diversification. That is why nowadays more and more agricultural holdings decide on developing market-oriented multi-function farming.

Figure 1
Number of Farms in Slovenia from 2003 to 2016

Source: SORS (2020)

All manners of increasing the financial and social stability by gaining income from various sources can be denominated with a common designation “diversification”. The predominant economic incentive for the diversification of agricultural holding is the expected increased income. This action, however, does not influence positively only a farming establishment but also offers numerous advantages for the broader region: the quality of life in the countryside (to improve the quality of life is also one of a strategic priority for the European Union), culture, tradition, and, last but not least, employment. Due to all the specifics of the agrarian structures according to Groot et al. (2009) these are mountainous and diverse terrain, the high proportion of karst areas) and lowering the factor incomes per employee in the agriculture (SORs, 2017), the farmers have to think hard about all the factors, not only economic ones, when they think about the step of diversification, especially if an investment would require more significant financial input. In the case of farm tourism as a method of diversification, thus, in addition to economic factors, neither environmental nor social nor socio-cultural factors are negligible (Žibert et al., 2020).

Not all farming establishments are appropriate for a step of this type of diversification. Žibert et al. (2020) researched the attributes of farming establishments for diversification to non-agricultural industries. Sharpley (2002) addresses the importance of long-term financial-technical aids and subsidies when developing farm tourism. Arroyo et al. (2013), Kheiri and Nasihatkon (2016) and Su et al. (2019) also addressed the importance of support services in their works. Muresan et al. (2016), Sharpley and Vass (2006) and Xue et al. (2017) study social context of the farmer’s attitude in connection with the diversification of the primary activity in tourism.
The development of supplementary activities at farm establishment related to tourism bears different advantages and disadvantages. That is why there exists a clear tendency of the use of modern supports in decision-making by which the proper directives can be ensured before bigger investment and activities affecting the environment. Using system dynamics, we can test different alternatives over time.

System dynamics methodology
Sterman (2000) says that systems thinking is necessary for efficient decision-making. Richmond (1993) speaks about systems thinking as about a multidimensional system where:

- We can think with models, which mean the ability to build a model and transfer the acquired knowledge into a real circumstance.
- We speak about dynamic thinking which enables anticipation of future behaviour of systems with all the delays, fluctuations, and feedback loops.
- We can understand a system as interrelated thinking where a single cause does not mean a single consequence. Consequences depend on a multitude of indirect influences.
- The system management – we understand the dimension of systems thinking as the most pragmatic component.
- Systems thinking and system dynamics observe the same types of problems. Contrary to the systems thinking, the system dynamics enables us – utilizing computer simulations of the models – a depiction of the behaviour of the real system when testing the effects of alternative decisions through time (Brailsford et al., 2014).

Forrester (1994) described the methodology of system dynamics by which we have followed in this research.

The idea of such modelling is based on the presumptions that every real system, as well as business systems, can be described by a whole of equations which are interconnected (Rozman et al., 2013; Rozman, et. al., 2015). Meanwhile, Sterman (2000) discussed modelling similarly in his work and described it as an iterative and standing part of the process of learning which is intended to setting the hypotheses and testing the formal and mental models. He described it with the following steps: Determination of a problem, Setting a dynamic hypothesis, Setting a simulation model, Testing, and Design of the strategy.

Results
Casual loop model
The development of complementary activities on the farm, especially if these are such where bigger financial investment (e.g. the development of tourism) is necessary not only on the level of farming establishment but also on the level of national and international policies, represents a dynamic and complex system which demands a developed ability of system thinking and the use of methods of system dynamics in order to determine and control the important issues.

Figure 2 represents the causal loop diagram of system structure – diversification of farming establishments in tourist farms with important consequences for the region and the farming establishment (Žibert et al., 2019).
According to an analysis of the environment (the study of practice) and following the previous research in this field (Sharpley, 2002) the simulation model should consider the key variables we have identified:

- The number of tourist overnight stays in the area,
- The number of agricultural holdings,
- The transition of the holding into a tourist farm,
- Subsidies,
- General organization and affection for tourism,
- The promotion of tourism,
- Environmental acceptability of rural tourism development

A key variable in the model is the number of tourist farms. This is a form with supplementary activity (which is catering activity) on the farm. From 2018 to 2019, the number of tourist farms in Slovenia increased from 1075 to 1126, although the number of farms has decreased. During the development of casual loop diagram, the key variables were identified:

- The number of potential farms (agricultural holdings) for diversification to farm tourism
- The number of tourist farms with
- The flow between them

In the system dynamics model (Figure 2), we can see several main feedback loops which represent reinforcing (R1, R2 and R3) and balance (B1 and B2). The loops R1, R2, and R3 indicate the developmental activity.
In reinforcing loop R1 increasing or growth of GDP influences investments in infrastructure directly, which has positive consequences on the environment mostly, as this is the way it is preserved more easily. Besides, the destinations are more easily accessible. At the same time, it influences environmental attractiveness. This attractiveness of the environment increases the demand for lodging and/or visiting destinations (reinforcing loop R2). Increasing the demand influences positively the decision of farming establishment whether it will diversify its primary industry. As already mentioned, this diversification influences economic effects, employability, and the quality of life positively. By the development of supplementary activity – farm tourism, the opportunities emerge for the development of other supplementary activities related to the cultivation of primarily agricultural crops, the sales of agricultural crops and products of farms, activities which are connected to traditional knowledge on farms, and social security services. Not all the farms’ establishments are suitable for the diversifying of tourism activities. However, as they expand their activities, there remains a smaller number of agricultural holdings that would exclusively deal with agriculture (B1).

An important variable of system structure is also the promotion factor (reinforcing loop R3). Not in the sense of promotion of the industry that tourism is the catalyst which would help in economic challenges of the countryside (Hoggart et al., 1995; Williams & Shaw, 1998), but in the sense of the promotion of tourist farms, destinations, the tradition of cultural habits, events, and environment whose part is the farming establishment itself. These are, therefore, the tools which are available to farms or broader groups of entities, and through which they communicate with their target publics about all the matters which influence the profitability and, primarily, the decision for the step of diversification (Podnar & Golob, 2001).

Despite everything, however, the share of GDP cannot entirely cover the investments in infrastructure which helps in the development of the tourist industry. Gartner (2004) reports on numerous support rates in the development of the industry. Despite that, however, the share of investments in infrastructure per unit shows one of the decisive equalization loops (B2). An important factor that decides whether a farm will diversify its primary activity and spread to the field of tourism is the revenue the farm receives. The latter is divided into several types. We speak about the profit the farm creates with its primary activity and about subventions that the farm can receive with the purpose to spread its activity. Subventions are a financial aid which farms receive from different sources (local, national or international). They can be onetime or long-lasting. Farms do not have to repay them. In the programming period 2014-2020 (RDP, 2014), the Rural Development Programme (it is a programming document of an individual member state of the EU which is the basis for the absorption of the financial funds from the European Agricultural Fund for Rural Development) anticipates some changes in a way that app. The amount of 10 million Euros of subventions would be allocated to farms in the Republic of Slovenia for the development of tourism in the countryside.

The next step in the system dynamics modelling process shows the system dynamics model for farm tourism development (as supplemented activities which are catering activities). It was based on the casual loop model presented in Figure 2.

**Model development**

A system dynamics model structure is shown in Figure 3. The methodology of system dynamics was defined by Forrester (1997) and Sterman (2000). The models of the system dynamics are composed of level elements that represent flows, stock, and levels of the system and auxiliary elements.
There are two levels present in the developed to the elements of the model. The variable “potentialFarmsForDiversification” represents the number of farms that are suitable for the transition. Farms in Slovenia with supplementary activity – tourism (which is catering activity) use 11.60 ha of utilized agricultural area (CAFES, 2017). We have identified the potential farm with acreage between 10 and 15 ha of utilized agricultural area. By the flow “Transition” the “potentialFarmsForDiversification” become “diversedFarms”. In 2018 there were 1,075 tourist farms (which was a catering activity) in Slovenia. One of the most important problems is the decreasing number of farms in Slovenia. On average, each year in the last period 1% of farms is lost (SORS, 2020). “PotentialFarmsForDiversification” has been influenced by the element “closingFarms”, which has been gotten by multiplying “ratioOfClosing” with the function “impactOfDiversificationOnClosing” and “potentialFarmsForDiversification”. Average yearly closing of farms in Slovenia from 2003 to 2016 is 2%. That presents an element “ratioOfClosing”. In the model, we have set it as a constant 0.02.

If the proportion diversification is larger, we expect, that the income will improve and fewer farms will close their business. When the ratio is present as potential: diversification = 5:1, 2% of potential farms leave the business. If income would be higher none would leave. That is what we present with the function “impactOfDiversificationOnClosing”. An element “RatioPotentialVsDiversed” represent input to the graph function “impactOfDiversificationOnClosing”. We get this ration by subtracting the number of farms that have diversified from farms that are suitable for the transition.

The flow “transition” in the model is associated with “noOfDecided”, which represents the number of farms that decide to make a transition. That number has been gotten by multiplying “concentrationOfPotentialFarms” with

Source: Author’s illustration
“farmsThinkingAboutTransition”, “percentageOfDetermined” and “attractivenessDueToSubsidies”. The concentrationOfPotentialFarms is obtained by dividing the number of potentialFarmsForDiversification by the totalNoOfFarms, where totalNoOfFarms present the sum of potential farms for diversification and diverse farms. The variable FarmsThinkingAboutTransition represents several farms that think about transition due to information spread. This variable has been getting by multiplying contactsToThink and diversifiedFarms. The element contactsToThink represents a constant. It has been set as a constant of 5. One new diverse farm triggers 2 other farms to consider the transition. Yearly, 1% out of 5415 potential farms for diversification turns to diversified. That would mean 54 farms.

“YearlyGrowthOfTourism” is input to the graph function percentageOfDetermined.

Effect of subsidies on the transitions represents the function attractivenessDueToSubsidies where an element percentageOfSubsidies represents its input. The proportion of diversification investment coverage represents a constant – percentageOfSubsidies, where its value in the model is 0.85.

Equations and parameters, as well as user defined functions, are quantified; the model is mathematically formulated (appendix).

Model calibration and validation
Validation of the model is an important part of the methodology (Forrester, 1994; Pejić-Bach & Ćerić, 2007; Rahmandad & Sterman, 2012; Sterman, 2000). To perform the validation the model was upgraded with the Mean Squared Error auxiliary variable and Cumulative Mean Squared Error level element which is shown in Figure 4.

Figure 4
A model with added Mean Squared Error auxiliary element and Cumulative Mean Squared Error level element

Source: Author’s illustration
Here we compared the estimated number of Farms with diversification from statistical data and simulation results in the period of ten years from 2008 to 2017. In the next step of the validation, we have used Powersim Solver with Genetic Algorithms, where we have varied the following parameters which are gathered in presented in Table 1. Here the initial value, as well as lower boundary and upper boundary, is shown. The target minimum value of the optimization was Cumulative of Mean Squared Error, i.e. we wanted that the difference between simulation and real data would be as small as possible.

Table 1
Parameters for optimization with Genetic Algorithms

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Init. value</th>
<th>Lower Boundary</th>
<th>Upper Boundary</th>
</tr>
</thead>
<tbody>
<tr>
<td>percentageOfSubsidies</td>
<td>0.5</td>
<td>0.2</td>
<td>0.95</td>
</tr>
<tr>
<td>yearlyGrowthOfTourism</td>
<td>0.0</td>
<td>0</td>
<td>0.15</td>
</tr>
<tr>
<td>contactsToThink</td>
<td>5</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>ratioOfClosing</td>
<td>0.01</td>
<td>0.001</td>
<td>0.02</td>
</tr>
</tbody>
</table>

Source: Author’s work

After the performed optimization with Genetic Algorithms, where we have used 100 generations with the same size of population the best parameters had the following values: percentageOfSubsidies =0.89, yearlyGrowthOfTourism = 0.085, contactsToThink = 4.5, ratioOfClosing = 0.019. Figure 5 shows a comparison of real data (1) and simulated (2) response to the best parameter set found by Genetic Algorithms optimization.

Figure 5
Comparison of real data (1) and simulated (2) response for the best parameter set found by Genetic Algorithms optimization

Source: Author’s illustration

In order to perform formal validation (Oliva, 2003; Pejić-Bach & Čerić, 2007) the Theil validation statistics (Oliva, 1995) was performed which results are reported in Table 2 One has to take into consideration that we have available only 10 points for validation. Therefore the $R^2$ value of 0.82 shows relatively good correlation. More
informative is Mean Abs. Percent Error which is only 6%; this is the average deviation from the real data.

Table 2
Theil validation statistics (Oliva, 1995) for the number of farms, that diversified

<table>
<thead>
<tr>
<th>Parameter: Number of Farms</th>
<th>N=10</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R^2$</td>
<td>0.82</td>
</tr>
<tr>
<td>Mean Abs. Percent Error</td>
<td>3736.9</td>
</tr>
<tr>
<td>Mean Square Error</td>
<td>61.13</td>
</tr>
<tr>
<td>Root Mean Square Error</td>
<td>0.01</td>
</tr>
<tr>
<td>Bias</td>
<td>0.03</td>
</tr>
<tr>
<td>Variation</td>
<td>0.34</td>
</tr>
<tr>
<td>Covariation</td>
<td>0.63</td>
</tr>
<tr>
<td>Source: Author’s work</td>
<td></td>
</tr>
</tbody>
</table>

In order to perform more thorough validation, the additional data should be gathered, however, the data is scarce in the field of Farm diversification. The appropriate data should be gathered by the Statistical Bureau of the Republic of Slovenia in order to perform additional validation tests of the model. Nevertheless, the computed Theil statistics provides promising results for future model development and shows the methodological approach to quantitative validation.

Scenario analysis
Table 3 shows parameter values for eight simulation scenarios SC1-SC8. The parameters that are varied are: percentageOfSubsidies, yearlyGrowthOfTourism, contactsToThink and ratioOfClosing. Change in parameters are shown with underline and grey table cell. Base values of the parameters were: percentageOfSubsidies = 50%, yearlyGrowthOfTourism = 8%, contactsToThink = 5 and ratioOfClosing = 1%.

Table 3
Scenarios with parameter values

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Percentage OfSubsidies</th>
<th>Yearly GrowthOfTourism</th>
<th>Contacts ToThink</th>
<th>Ratio OfClosing</th>
</tr>
</thead>
<tbody>
<tr>
<td>SC1</td>
<td>25</td>
<td>0.08</td>
<td>5</td>
<td>0.01</td>
</tr>
<tr>
<td>SC2</td>
<td>95</td>
<td>0.08</td>
<td>5</td>
<td>0.01</td>
</tr>
<tr>
<td>SC3</td>
<td>50</td>
<td>0.04</td>
<td>5</td>
<td>0.01</td>
</tr>
<tr>
<td>SC4</td>
<td>50</td>
<td>0.15</td>
<td>5</td>
<td>0.01</td>
</tr>
<tr>
<td>SC5</td>
<td>50</td>
<td>0.08</td>
<td>1</td>
<td>0.01</td>
</tr>
<tr>
<td>SC6</td>
<td>50</td>
<td>0.08</td>
<td>10</td>
<td>0.01</td>
</tr>
<tr>
<td>SC7</td>
<td>50</td>
<td>0.08</td>
<td>5</td>
<td>0.005</td>
</tr>
<tr>
<td>SC8</td>
<td>50</td>
<td>0.08</td>
<td>5</td>
<td>0.02</td>
</tr>
</tbody>
</table>

Source: Author’s work

Results of eight scenarios are shown in Figure 6. On the left side, the number of Farms with diversification is shown, in the middle the intensity of Farm closing is shown and on the right side the transition from potential Farms to Farms with diversification is shown. On the x-axis, the time is shown with the unit 1 [year]. One can observe, that SC1, SC3 and SC5 result in low transition rates, SC7 and SC8 provides moderate growth and SC2, SC6 and SC4 provide fast growth of the number of Farms with Diversification.
By the provided results, one can identify the main driving forces of the system, which are: a) subsidies, b) Tourism branch growth and c) Promotion of diversification. It is also interesting, that larger intensity of closing of the farms would also lead to lower transition rates which are not desirable.

**Discussion**

There are many equal depictions for the computer simulation of systems. A display of the casual loop model is the foundation for qualitative modelling. In our article, we explained the course and the dynamics of the process of diversification on non-agricultural activities on the farm.

It is almost sure that the parameters, that we used in different scenarios will not remain constant for that long period. One of the important findings is that the system is sensitive to changes in subsidies, promotion of diversification and with the growth of Tourism branch. Promotion of diversification means the policy for promoting the development of supplementary activities at farms (related to tourism). Also according to Gunn (1988), tourism development (also farm tourism) involves several components to be successful: attractions, tourism infrastructure, services, hospitality and promotion. The importance of promotion is also perceived in the casual loop model as a positive feedback loop. The “ratioOfClosing” represent the average yearly closing of farms in Slovenia. This value is initially set to 0.01. As we explained by model development description, the yearly average closing of farms in Slovenia from 2003 to 2016 is 2%. The “yearlyGrowthOfTourism” present the yearly average growth of tourism. In Slovenia from 2010 to 2018 is 8%. We have set it as a constant 0.8. In the case, that the yearly growth of tourism branch is 8%, the growth in new diversified farms is approximately 1%. This can be also used, with some correction, as the part, which determines how many of those who think about the transition will perform the transition. SC4 shows the impact of greater yearly growth of tourism. According to SC4, the largest transition would be achieved in 15 years.

Comparing scenarios SC1, SC2 and SC3, which shows a distinct subsidy rate, more intensive transition is observed. The more subsidies, the greater and faster is the transit from potential to diverse farms. In scenario SC3, the impact of decreasing the “yearlyGrowthOfTourism” is considered. Scenario SC3 is familiar to scenario SC5, but with the differences in two elements − in “yearlyGrowthOfTourism” and in “contactsToThink”. In both cases, one of the factors (contact to think or yearly growth of tourism) is really low. One more time it shows a testament to how important these two factors are for our transit. Scenarios SC7 and SC8 provides moderate
growth. Due to the lower “ratioOfClosing” scenario, SC7 achieves higher farm transition, which is understandable.

Our research has certain limitations. The data is scarce in the field of Farm diversification in Slovenia, especially in the field of tourism. The appropriate data should be gathered by the Statistical Bureau of the Republic of Slovenia, but in 2015, the policy of introducing supplementary activities changed and many of the data of recent years are irrelevant or difficult to compare. And behind that, this system dynamics model is partially related to the causal loop model and covers only the main feedback loops B1 and R1. This model does not provide numerical forecasts. It is rather a policy tool that examines the behaviour of key variables over time. Furthermore, models explain why specific outcomes are achieved.

Today, tourism and complementary activities enable a large percentage of GDP. A sensible question emerges where there is a boundary until this growth can endure and, consequentially, how many tourists can accept a certain area. Namely, these answers are necessary so that we can further think about the element of subvention and about the amounts by which the farms would finance by themselves with the purpose of the development of additional non-agricultural contents in farming establishments.

Conclusion

In this paper, we presented a qualitative causal loop model and a system dynamics model used for the simulation of transition of farming establishments in tourist farms for the purpose of increasing profitability through the diversification. The system dynamics model enables the simulation of the behaviour of the real system when testing the effects of alternative decisions in time.

After performing several simulation scenarios, we discovered that transition to diverse farms relies on subsidies that provide the main motivation for the transition. However, the subsidies are not the only driving force in the system; there are also two other elements: rate of tourism growth and promotion of diversification. One of the important advantages represented by the system dynamics model is the ability of the response of the target variables in certain periods. It is a useful tool for decision-makers in connection with the further development of tourism in the countryside.

Comparison with previous research (Goeldner & Ritchie, 2007; Ritchie & Zins, 1978) identified the main variables which considered the development of tourism activities in the rural area. But, in addition to recognizing them, we have also shown the impact they have on each other when developing tourism through agricultural diversification.

In summary, our work indicate that the dynamic response of the system should be taken into account in further strategic decisions regarding the development of tourism farms. In particular, the role of subsidies, tourism branch growth and promotion of diversification must be taken into account. We can conclude that the system dynamics model can be regarded as a useful decision support tool for policymaking. Scenario results indicated that an important factor that influences the downward trend in the number of agricultural holdings is farm income, which can be improved by diversification. However, the model has its limitations, that mainly stem from the fact that this system dynamics model is only partially related to the causal loop model and covers only the main feedback loops. Therefore, to further development of a model, that will predict even the broad range of various scenarios, more versatile model should be developed, incorporating sectors, such as sustainability and impact to the demography.
References
European Association of Agricultural Economists, 30 January-1 February, EAAE, Sevilla, Spain.


38. RDP. (2014), Rural Development Programme, available at: https://www.program-podezelja.si/images/SPLETNA_STRAN_PRP_NOVA/1_PRP_20142020/1_1_Kaj_je_program_razvoja_pode%C5%BEelja/7_sprememba_PRP/Programme_2014SI06RDNP001_9_1_sl.pdf (16 April 2020)


42. SORS. (2017), “In 2017 the real factor income per employee in agriculture expected to decrease by 15% over 2016”, available at: https://www.stat.si/statweb/News/Index/7109/ (7 June 2019)


About the authors

Maja Žibert achieved her master study at the University of Maribor, Faculty of Tourism. Currently, she is a PhD student in agrarian economics (Faculty of Agriculture and Life Sciences, University of Maribor). She is active as a teaching assistant at the Faculty of the Tourism University of Maribor. Her research includes papers in destination management, wine tourism, rural tourism area and system dynamics. In year 2014/2015 she was regional Wine Queen of Slovenia and in 2017 she was Slovenian Wine Queen. The author can be contacted at maja.zibert@student.um.si

Črtomir Rozman received his PhD at the University of Maribor, Faculty of Agriculture. He is active as a full professor of farm management in the Department for Agriculture Economics and Rural Development. His research includes the development of decision-support systems for farm management (simulation modelling, multi-criteria decision analysis, machine learning) and the economics of agricultural production. He is the author or co-author 86 scientific papers, 43 with journal citation report impact factor. He is also an author or co-author of 7 scientific books and 25 book chapters. The author can be contacted at crt.rozman@um.si

Andrej Škraba obtained his BSc, MSc and PhD in the field of Organizational Sciences – Informatics from the University of Maribor in 1995, 1998, and 2000, respectively. He works as a professor and researcher in the Cybernetics & Decision Support Systems Laboratory at the University of Maribor, Faculty of Organizational Sciences. His research interests cover systems theory, modelling and simulation, cyber-physical systems, the internet of things and decision processes. Prof. Škraba has received a Bronze Medal of University of Maribor, for successful research and pedagogical work in the field of Systems Modeling and Simulation in 2003. He is a member of the System Dynamics Society (SDS) and the Slovenian Society for Simulation and Modelling (SLOSIM). The author can be contacted at andrej.skraba@um.si

Boris Prevolšek is a teaching assistant and lecturer at the Faculty of Tourism, the University of Maribor in Brežice. He received his Master of Science in 2012 from the Faculty of Economics and is currently enrolled in his PhD Studies at the Faculty of Agriculture and Life Sciences of the University of Maribor. As a researcher, he is interested in various topics concerning tourism, also safety in tourism and rural development. He co-authored 6 scientific papers, 2 scientific books and 4 book chapters. The author can be contacted at boris.prevolsek@um.si
Appendix 1. Model Equations

\[ \text{init} \quad \text{diversedFarms} = 1075 \]
\[ \text{flow} \quad \text{diversedFarms} = +dt*\text{Transition} \]
\[ \text{doc} \quad \text{diversedFarms} = \text{Farms that have diversified.} \]
\[ \text{unit} \quad \text{diversedFarms} = \text{farm} \]
\[ \text{init} \quad \text{potentialFarmsForDiversification} = 5415 \]
\[ \text{flow} \quad \text{potentialFarmsForDiversification} = -dt*\text{closingFarms} - dt*\text{Transition} \]
\[ \text{doc} \quad \text{potentialFarmsForDiversification} = \text{Farms that are suitable for transition, acreage between 10ha and 15ha.} \]
\[ \text{unit} \quad \text{potentialFarmsForDiversification} = \text{farm} \]
\[ \text{aux} \quad \text{closingFarms} = \text{ratioOfClosing*impactOfDiversificationOnClosing*potentialFarmsForDiversification} \]
\[ \text{aux} \quad \text{Transition} = \text{noOfDecided} \]
\[ \text{doc} \quad \text{Transition} = \text{Transition from conventional farm to diversified.} \]
\[ \text{unit} \quad \text{Transition} = \text{farm/year} \]
\[ \text{aux} \quad \text{attractivenessDueToSubsidies} = \text{GRAPH(percentageOfSubsidies,0,0.1,[0,0,0.04,0.28,0.77,1,1.08,1.13,1.23,1.4,2"Min:0;Max:2")}} \]
\[ \text{doc} \quad \text{attractivenessDueToSubsidies} = \text{Effect of subsidies on the transitions} \]
\[ \text{aux} \quad \text{concentrationOfPotentialFarms} = \text{potentialFarmsForDiversification/totalNoOfFarms} \]
\[ \text{aux} \quad \text{farmsThinkingAboutTransition} = \text{contactsToThink*diversedFarms} \]
\[ \text{doc} \quad \text{farmsThinkingAboutTransition} = \text{Number of farms, that think about transition due to information spread.} \]
\[ \text{unit} \quad \text{farmsThinkingAboutTransition} = \text{contact/year} \]
\[ \text{aux} \quad \text{impactOfDiversificationOnClosing} = \text{GRAPH(ratioPotentialVsDiversed,0.1,[0,0.08,0.14,0.28,0.62,1,1.33,1.55,1.76,1.92,2"Min:0;Max:2")}} \]
\[ \text{doc} \quad \text{impactOfDiversificationOnClosing} = \text{If the proportion diversification is larger, we expect, that the income will improve and less farms will close their business. When ratio is present as potential:diver=5:1, the 2% of potential farms leaves the business. If income would be higher none would leave.} \]
\[ \text{unit} \quad \text{impactOfDiversificationOnClosing} = \text{dmnl} \]
\[ \text{aux} \quad \text{noOfDecided} = \text{concentrationOfPotentialFarms*farmsThinkingAboutTransition*percentageOfDetermined*attractivenessDueToSubsidies} \]
\[ \text{doc} \quad \text{noOfDecided} = \text{Number of farms that decided to make a transition.} \]
\[ \text{unit} \quad \text{noOfDecided} = \text{farms/year} \]
\[ \text{aux} \quad \text{percentageOfDetermined} = \text{GRAPH(yearlyGrowthOfTourism,-0.02,0.02,[0,0.0012,0.0014,0.0025,0.0055,0.01,0.0146,0.02,0.0243,0.0263,0.027"Min:0;Max:0.03")}} \]
\[ \text{doc} \quad \text{percentageOfDetermined} = \text{Yearly growth of tourism si input to the graph function. In the case, that the yearly growth of tourism branch is 8%, the growth in new diversified farms is approximately 1%. This can be also used, with some} \]

147
correction, as the part, which determines how many of those who thing about transition will actually perform the transition.

unit \( \text{percentageOfDetermined} \) = \( \text{dmnl} \)

aux \( \text{ratioPotentialVsDiversed} \) = potentialFarmsForDiversification/diversedFarms

aux \( \text{totalNoOfFarms} \) = potentialFarmsForDiversification+diversedFarms
do\( c \) \( \text{totalNoOfFarms} \) = Sum of potential farms for diversification and diversified farms.

unit \( \text{totalNoOfFarms} \) = farm

const \( \text{contactsToThink} \) = 5
do\( c \) \( \text{contactsToThink} \) = One new diversified farm triggers 2 other farms to consider transition. Yearly, 1% out of 5415 potential farms for diversification turns to diversified. That would mean 54 farms.

unit \( \text{contactsToThink} \) = contacts/farm/year

const \( \text{percentageOfSubsidies} \) = 0.85
do\( c \) \( \text{percentageOfSubsidies} \) = Proportion of diversification investment coverage.

unit \( \text{percentageOfSubsidies} \) = \( \text{dmnl} \)

const \( \text{ratioOfClosing} \) = 0.02
do\( c \) \( \text{ratioOfClosing} \) = Average yearly closing of farms in Slovenia from 2003 to 2016 is 2%.

unit \( \text{ratioOfClosing} \) = \( \text{dmnl} \)

const \( \text{yearlyGrowthOfTourism} \) = 0.08
do\( c \) \( \text{yearlyGrowthOfTourism} \) = Average yearly growth of tourism in Slovenia from 2010 to 2018 is 8%.

unit \( \text{yearlyGrowthOfTourism} \) = \( \text{dmnl} \)

spec \( \text{start} = 0.00000 \)
spec \( \text{stop} = 50.00000 \)
spec \( \text{dt} = 1.00000 \)
spec \( \text{method} = \text{Euler (fixed step)} \)
Abstract

Background: To stay competitive in a highly unpredictable market of today, companies must be able to manage project risks effectively. The basis for an effective risk management is a thorough risk analysis. Despite the availability of many different risk analysis approaches, companies can be reluctant to use them, since the models are usually complex and very time consuming. Objectives: The main objective is to present a simple, yet effective risk analysis approach that can also serve as a useful basis for resolving project risks. Methods/Approach: The proposed standard risk analysis approach is based on a standard risk model that deals with risk events and impacts separately and therefore allows for a separate planning of preventive and corrective measures. To classify risks and to represent them graphically, a risk map is used. Results: The use of the proposed approach is illustrated on a die-cast tool development project. The approach proved to be very simple to use and it served as a useful basis for resolving the identified risks. Conclusions: The main advantage of the proposed approach is its simplicity and clarity. It can also be used as a quick decision-making tool in a subsequent risk resolving process.

Keywords: risk management, risk analysis, standard risk model, risk map

JEL classification: O22, O32

Paper type: Research article

Received: Nov 22, 2019
Accepted: Apr 19, 2020


DOI: 10.2478/bsrj-2020-0021

Acknowledgments: This work was supported by the Ministry of Higher Education, Science and Technology of the Republic of Slovenia, Grant No. 1000-15-0510, and by the Slovenian Research Agency, Grant No. P2-0270.

Introduction

Today, companies are facing more and more complex products, rapid technology changes, ever changing customer demands and unpredictable markets. To survive and remain competitive, companies have to be able to adapt to the competitive
environment and to manage uncertainties. Risks are one of the key success factors of a project (Krane et al., 2010), therefore it is crucial that they are effectively managed.

Merritt and Smith (2004) defined a risk in the context of a project as a possibility of occurrence of an undesired event or a possibility of the absence of a desired event, and the risk management as a set of techniques for controlling the project uncertainties.

PMBOK® lists risk management as one of the basic areas of successful project management skills (PMI, 2017). Project managers need to be trained to use the appropriate risk management tools throughout the project and not only when adverse effects occur.

A widely accepted risk management process consists of the following five steps: risk identification, risk analysis, risk prioritization, resolving risks, and monitoring risks (Smith and Merritt, 2002; Tonchia, 2018). In this paper, we are going to focus on the risk analysis step.

The risk analysis step is very important, because the companies have neither time nor resources for resolving all of the identified risks. Therefore, risks must be properly evaluated, and resources used only on resolving the most critical ones (Baccarini & Archer, 2001).

There are many different risk analysis methods available (Chauhan et al., 2018; de Araújo Lima et al., 2019). Some of them evaluate risks qualitatively and others quantitatively (de Araújo Lima et al., 2019). In general, quantitative methods provide results that are more objective yet they rely on detailed numerical data that is rarely available. Therefore, experts’ assessments are often applied as an alternative to the objective data (Ferdous et al., 2011). Chauhan et al. (2018) state that experts can be a reliable source of information as they are working on the projects on a daily basis.

In practice, a risk matrix is one of the most widely used risk evaluation tools (Levine, 2012; Li et al., 2018). Risks are categorized into different risk cells, to which specific risk levels are assigned (usually low, moderate, high), based on the evaluation of two components: the probability of risk occurrence and the magnitude of impact (Li et al., 2018). The evaluation can be either qualitative, semi-quantitative, or quantitative (Ni et al., 2010). When quantitative evaluation is applied, a risk matrix can be extended into a continuous graph, called a risk map (Smith & Merritt, 2002).

One of the drawbacks of a risk matrix approach is that the same quantitative risks can fall into different qualitative risk cells (Levine, 2012). This problem can be solved with a different partition of the matrix: the risk areas, to which the same risk level is assigned should not be rectangular cells but irregularly shaped areas, separated by hyperbolas (Ni et al., 2010; Levine, 2012). These hyperbolas, also called the isorisks (Levine, 2012), connect risks with the same quantitative score.

Another possible upgrade of a risk evaluation process is to treat a risk as a combination of two separate entities: a risk event and an impact. With a clear separation between a risk event (cause) and an impact (effect), preventive and corrective measures can be prepared more effectively. Smith and Merritt (2002) call this risk evaluation model a standard risk model.

In this paper, we are going to present a risk analysis approach that combines a standard risk model and a risk map. This combination allows for a simple risk evaluation that supports the cause and effect concept, and provides for a consistent risk categorization. The main aim is to present the proposed approach, and to illustrate its use on a real case example. We want to show that the approach is simple to understand, offers a quick and illustrative risk evaluation, and serves as a good platform for resolving risks.
The rest of the paper is organized as follows: in the next section, the standard risk model and risk map are described. Next, the standard risk analysis approach is shown on a die-cast tool development project. Finally, in the discussion and the conclusion, the advantages and disadvantages of the approach are discussed and some directions for a future research provided.

**Methodology**

**Standard Risk Model**

A risk model is a tool for systematic risk management. It facilitates communication between stakeholders and allows for an easier risk identification and analysis (Smith & Merritt, 2002).

In most cases, risks are treated as a combination of risk probability and risk impact (Markowski & Sam Mannan, 2008; Ni et al., 2010). This model is referred to as a simple risk model (Smith & Merritt, 2002). While it is simple to use, this model can also lead to some confusion when resolving risks, since it is very hard to distinguish between the cause and the effect. Smith and Merritt (2002) therefore recommend the use of a standard risk model, where the risk event (cause) and the impact (effect) are dealt with separately.

The standard risk model is shown in Figure 1. It relates three entities: the risk event, the impact, and the total loss. The risk event represents the state that triggers a potential loss, the impact represents a potential consequence of the risk event, and the total loss ($L_t$) represents the severity of the loss in case of the risk event occurrence. For the risk event and the impact, the drivers must be identified and the probabilities of occurrence determined ($P_e$ and $P_i$).

![Figure 1: Standard Risk Model](image)

Source: Smith and Merritt (2002)

The probabilities $P_e$ and $P_i$, and the total loss $L_t$ represent subjective assessments, since the objective values are in most cases not available (Ferdous et al., 2011). The assessments are usually based on the experience from previous similar projects, or on decision-making tables prepared by an expert group. Even though the assessments are subjective in nature, they can still support the decision-making (Aven, 2016). The assessed values $P_e$, $P_i$ and $L_t$ represent the basis for evaluating the expected loss of the risk $L_e$, which indicates its severity (Smith & Merritt, 2002):

$$L_e = P_e \cdot P_i \cdot L_t$$ (1)
Risk Map
The number of identified risks is usually high, while the available resources for dealing with risks are limited. Therefore, the risks need to be properly classified and resources need to be focused on those risks that pose the greatest danger to the project (Baccarini & Archer, 2001).

One of the simplest risk prioritization tools is a risk matrix (Levine, 2012). The x axis of a risk matrix represents the magnitude of impact, and the y axis represents the risk probability. The risk matrix is sectioned into cells that are assigned different risk ratings (usually low, moderate, high), based on the evaluation of the two components (Li et al., 2018).

The magnitude of impact and the risk probability can be evaluated qualitatively, semi-quantitatively, or quantitatively (Ni et al., 2010). When a standard risk model is used, the evaluation is quantitative, and a risk matrix can be transformed into a continuous graph, called a risk map (Smith & Merritt, 2002). According to the standard risk model, the x axis of a risk map represents the total loss $L_t$ (it can be expressed in units of time, money or quality), and the y axis represents the risk likelihood, which equals the product of the risk event probability $P_e$ and the risk impact probability $P_i$.

In contrast to the risk matrix, the risk map is not sectioned into predefined risk cells, but into irregularly shaped areas separated by hyperbolas (Ni et al., 2010). Thus, a consistent colouring is ensured (Levine, 2012).

The hyperbolas represent the lines with a constant expected loss. This means that all the risks that lie on the same hyperbola lead to the same expected loss. The hyperbolas are also called the isorisks and are defined with the following equation (Levine, 2012):

$$\frac{L_e}{L_t} = P_e \cdot P_i$$  \hspace{1cm} (2)

Using a risk map, project risks can be classified into any number of categories. The simplest classification is a classification into two categories only: critical risks and non-critical risks (Figure 2). In a risk map, critical and non-critical risks are separated by a hyperbola called a threshold line (Smith and Merritt, 2002). The threshold line is defined with equation 2, where $L_e$ equals the still acceptable loss for the company.

![Figure 2: Risk Map](image-url)
The area above the threshold line represents the critical risk area (Risk 1 in Figure 2), and the area below the threshold line represents the non-critical risk area (Risk 2 in Figure 2). For critical risks, adequate measures, both preventive and corrective, need to be prepared to reduce the risk level. The risk level can be reduced by either lowering the risk event probability, the impact probability or by lowering the total loss. The goal is for all the risks to be below the threshold line in the non-critical risk area.

**Results: A Die-Cast Development Project**

In the following, the use of the standard project risk analysis approach is shown on a development project of a die-cast tool for an automotive engine component production. The tool was developed and manufactured in a Slovenian SME toolmaking company. The project started with an order from the customer and completed with the confirmation of product samples.

First, the major risk factors (project team, buyer, suppliers, development and technology, manufacture, quality control) were identified using the Ishikawa diagram, and all the possible project risks within the individual factors were found. Then the Work Breakdown Structure (WBS) of the project was thoroughly studied and the identified risks were assigned to individual activities.

According to the standard risk model, the identified risk events were linked to their impacts. Based on the experience with similar projects, the project team assessed the risk event probability $P_e$, the impact probability $P_i$, and the total loss $L_t$. Using the assessed values, the expected loss $L_e$ for each risk was calculated using equation 1. The risks were then prioritized by the value of the expected loss. Both, the monetary losses (additional costs) and time losses (delays) were analysed. For illustrative purposes, only the analysis of four monetary-loss related project risks is presented in the following. These risks are summarized in Table 1.

<table>
<thead>
<tr>
<th>Risk</th>
<th>Activity</th>
<th>Risk Event Description</th>
<th>$P_e$</th>
<th>Impact Description</th>
<th>$P_i$</th>
<th>$P_e$ $P_i$</th>
<th>$L_t$ [€]</th>
<th>$L_e$ [€]</th>
</tr>
</thead>
<tbody>
<tr>
<td>R1</td>
<td>Design Freeze</td>
<td>Late confirmation of documentation by the buyer</td>
<td>0.8</td>
<td>Plan for the tool not prepared in time</td>
<td>0.9</td>
<td>0.72</td>
<td>5,000</td>
<td>3,600</td>
</tr>
<tr>
<td>R2</td>
<td>Confirma-</td>
<td>Rejection by the buyer</td>
<td>0.3</td>
<td>Corrections of the method</td>
<td>1.0</td>
<td>0.30</td>
<td>5,000</td>
<td>1,500</td>
</tr>
<tr>
<td></td>
<td>tion of first pieces</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R3</td>
<td>Manufacture of first pieces</td>
<td>Poor quality of pieces</td>
<td>0.5</td>
<td>Corrections of the method, new manufacture of pieces</td>
<td>0.8</td>
<td>0.40</td>
<td>3,000</td>
<td>1,200</td>
</tr>
<tr>
<td>R4</td>
<td>Delivery of special tool</td>
<td>Late delivery</td>
<td>0.6</td>
<td>Manufacture of special parts not in time</td>
<td>0.7</td>
<td>0.42</td>
<td>500</td>
<td>210</td>
</tr>
</tbody>
</table>

Note: For illustrative purposes, only four monetary-loss related risks are listed. The values $P_e$, $P_i$, and $L_t$ were assessed by the project team.

Source: Author’s work
The still acceptable expected loss $L_e$ was set at €1,000. The risk map of the risks listed in Table 1 is shown in Figure 3. One can quickly see that risks R1, R2 and R3 are critical (they lie above the threshold line), while risk R4 is not critical (it lies below the threshold line).

**Figure 3**
Monetary-Loss Related Risk Map for the Die-Cast Tool Development Project

For the most critical risks, a detailed analysis has been made, risk event drivers and affect drivers identified, and different measures to lower the risk levels prepared. A detailed analysis will be illustrated on the example of risk R1. Risk R1 is the most critical among the listed risks and it appears as first in the project’s timeline. The standard risk model for risk R1 is presented in Figure 4.

![Risk Map](source)

It is a known fact that the buyer often confirms the documentation later than originally agreed. Based on the previous experience with the buyer, the project team assessed there is an 80% chance that the confirmation will be received with a 2-week delay.

Without the documentation being confirmed, the plan for the tool cannot be completed and the work cannot continue according to the foreseen schedule, which leads to high extra costs. If the buyer is two weeks late with the confirmation, the total loss of the company is assessed to amount to €5,000. The expected loss equals €3,600, which is higher than the predetermined still acceptable value of €1,000. Therefore, adequate measures had to be prepared to lower the expected loss.

First, the risk event drivers were analysed. It turned out that the main reason for the late confirmation of the documentation lies in the fact that the timelines of the buyer are not harmonised with those of the company. It was decided to coordinate the dates before signing the contract and to have the dates fixed in the contract (measure 1). The project team assessed that the probability for the documentation not being confirmed in time reduces to 70%, and at the same time half of the costs are passed on to the buyer in case of a delay. The total loss in that case equals €2,500, and the expected loss equals €1,575.
In the next step, the impact of the late confirmation of the documentation was analysed. If the documentation is not confirmed in time, then the plan for the tool will almost certainly not be prepared according to schedule. This further leads to overtime and delays in all the following activities, and the additional cost get very high. To lower the probability of the impact, it was decided to send a written request in case the buyer is still late in confirming the documentation, despite the harmonized timelines (measure 2). In that case, the buyer usually provides the confirmation quite rapidly, and the probability for the tool plan not being prepared in time was assessed to reduce to 50 %. The expected loss is thus lowered to €875, which is within the safe area.

The results of the prepared measures are summarized in Table 2. The basic risk is denoted with R1, the risk after the measure 1 with R1.1, and the risk after the measure 2 with R1.2. The impact of the measures is also evident on the risk map shown in Figure 5.

**Table 2**
Resolving risk R1: Impact of the planned measures on the expected loss

<table>
<thead>
<tr>
<th>Risk</th>
<th>$P_e$</th>
<th>$P_i$</th>
<th>$P_e \cdot P_i$</th>
<th>$L_i$ [€]</th>
<th>$L_e$ [€]</th>
</tr>
</thead>
<tbody>
<tr>
<td>R1</td>
<td>0.8</td>
<td>0.9</td>
<td>0.72</td>
<td>5,000</td>
<td>3,600</td>
</tr>
<tr>
<td>R1.1</td>
<td>0.7</td>
<td>0.9</td>
<td>0.63</td>
<td>2,500</td>
<td>1,575</td>
</tr>
<tr>
<td>R1.2</td>
<td>0.7</td>
<td>0.5</td>
<td>0.35</td>
<td>2,500</td>
<td>875</td>
</tr>
</tbody>
</table>

Source: Author’s work
**Discussion**

The use the standard project risk analysis approach was shown on the die-cast tool development project. The approach was used for a quick evaluation and prioritization of the identified project risks, and it served as a very helpful basis for resolving risks. The graphical representation of risks allowed for a quick identification of the critical risks and therefore enabled a quick decision, on which risks to focus. With different preventive measures (measure 1) and corrective measures (measure 2), the project team managed to significantly lower the risk levels.

The main advantage of the approach is its simplicity. The severity of the identified risks can be quickly evaluated according to the standard risk model. The calculations are simple and rather intuitive even to a non-expert. The quantification of loss is also very beneficial when prioritizing project risks.

Another great advantage of the standard risk model is a separate treatment of the risk event and the impact, which clarifies the cause and the effect, and thus allows for a separate planning of preventive and corrective measures (Merritt & Smith, 2004). The effect of individual measures can be easily monitored on the risk map.

The proposed approach is also very transparent and clear. In the risk map, one can instantly find the critical risks that need special attention. The introduction of the isorisks makes sure that the risks that lead to the same expected loss fall in the same risk area. In that sense, the presented approach can also serve as a reliable decision-making prompt.

However, the approach has some drawbacks. First, one must be aware that the assessments of the probabilities and total losses are subjective in nature and can lead to a significant error. The error can be lowered to some extent with the introduction of discrete scales and expert groups, however, the results always represent just a rough estimate.

Second, the standard risk model does not allow multiple risk events to converge on a single impact (Smith & Merritt, 2002). In addition, the correlations between different risks are not taken into account. If a risk is treated as a single isolated entity, it may seem rather insignificant, even though it can be correlated to other highly critical risks.
The correlations between risks are crucial for effective risk management and will be addressed in further research.

**Conclusion**

Effective risk management is a key to a successful project. One of the basic steps of a risk management process is a risk analysis. In the paper, we presented a standard project risk analysis approach that combines a standard risk model and a risk map. The use of the presented risk analysis approach was illustrated on a die-cast tool development project and it proved to be very useful. The analysed project was rather simple and the main goal was to get an evaluation of risks levels quickly. For more complex projects, the developed approach might not be sufficient and at least an additional correlation analysis should be made.

Even though there are some drawbacks to the proposed approach, it can be very helpful when a quick risk evaluation must be made. The separate treatment of risk events and impacts also allows for an easier and more effective planning of preventive and corrective measures and therefore serves as a good basis for resolving risks in the following steps of a risk management process.

**References**

About the authors

Tena Žužek is a PhD student and a young researcher in the Laboratory for Manufacturing Systems and Production Process Planning at the Faculty of Mechanical Engineering, University of Ljubljana. She received a bachelor’s degree in physics and a master’s degree in mechanical engineering from the University of Ljubljana. Her research interests include project management, risk management, concurrent engineering and agility. The author can be contacted at Tena.Zuzek@fs.uni-lj.si

Lidija Rihar graduated from the Faculty of Mechanical Engineering of Ljubljana in the field of production systems in 2009. In 2013, she defended her doctoral dissertation entitled Generalized Model of Concurrent Product and Process Development. Her research fields include project management, concurrent engineering and teamwork. Since 2013, she has been a research assistant at the Faculty of Mechanical Engineering in the field of production systems. The author can be contacted at Lidija.Rihar@fs.uni-lj.si

Tomaž Berlec, Ph.D. is an assistant professor at the Faculty of Mechanical Engineering, University of Ljubljana, Slovenia. He obtained his M. Sc. degree in 2003 and a Ph.D. degree in 2008 in the field of production planning and control. His research fields include: lean production, teamwork, material flow optimisation in companies with individual and small-series production, lead times optimisation of operations and orders, production planning and control systems. In these fields, he published 21 original scientific papers in scientific journals and more than 60 papers in conference proceedings. The author can be contacted at Tomaz.Berlec@fs.uni-lj.si

Janez Kušar is an associate professor at the Faculty of Mechanical Engineering, University of Ljubljana, Slovenia. He took his Ph.D. in 1999 in the field of production planning and control. His research fields include project management, especially in individual and small-series production, material flow optimization, production planning and control systems, and projects of transition from sequential to concurrent engineering. In these fields, he published more than 20 original scientific papers in scientific journals and more than 60 papers in conference proceedings. He is a member of the IPMA – International Project Management Association and ICEC – International Cost Engineering Council. The author can be contacted at Janez.Kusar@fs.uni-lj.si
An Investigation of Business Process Maturity: Report on Croatian Companies

Ljubica Milanović Glavan
University of Zagreb, Faculty of Economics and Business, Croatia

Abstract

Background: Nowadays, organizations try to improve their performance by focusing on the business process orientation (BPO) perspective. This perspective views companies as a mixture of unified business processes. A few methodologies can be used for analysing BPO maturity state. The maturity model shows the level of acceptance of the process-oriented approach in the business practice of a certain company. Recognizing different BPO levels can help companies execute, improve and manage their processes. Objectives: The primary aim of this research is to give a report on BPO maturity of Croatian companies and to stress the importance of key turning points. Methods/Approach: The cluster analysis method was used to analyse the survey results. Results: Croatian companies are currently evolving from the Defined level to the Linked level of BPO maturity. Conclusions: The results of the cluster analysis have shown that companies in Croatia have to improve all key turning points, with a special emphasis on the strategic view.

Keywords: process management, business maturity, cluster analysis, Croatian companies, turning points.

JEL classification: M15, M21
Paper type: Research article
Received: Jan 28, 2020
Accepted: Jul 6, 2020

Introduction

Business process management literature review shows that BPO has a positive effect on business performance (Hernaus et al., 2012; McCormack & Johnson, 2001; Milanović Glavan & Bosilj Vukšić, 2017). The absolute definition of BPO was provided by McCormack (2001) and it says that BPO presents the position in which an organization is focused on its business processes.

Process maturity is a more extensive version of business orientation which implicates that reaching higher stages of maturity means higher levels of process skills for the company. In every maturity level, it is of crucial importance to recognize and improve key turning points or maturity components that lead companies to the next level. The literature reveals that empirical research regarding key turning points...
is not frequent. Some research was done before in Croatia by using decision tree method and it proved that in order to reach all BPO maturity levels companies have to focus on: “Human resources”, “Supplier orientation”, “Process measurement”, and “Computer technology” (Milanović Glavan et al., 2015). The research conducted by McCormack et al. (2009), identified key turning points by using different statistical methods. One of the approaches used in that study was cluster analysis and it was elaborated that it is the best method to detect key turning points. So, according to the cognition, that cluster analysis method can detect important maturity components, previous research in Croatian companies was extended and the data were analysed by using the cluster approach. The prime plan of the new research is to reply to the research question: RQ: Which maturity components are the most critical for each maturity level?

By answering this, it is expected to accomplish the specified scientific objectives: first, investigate the level of maturity in Croatia; second, to address key turning points by using cluster analysis method; third, to procure potential future research in this field.

This research provides a scientific contribution since it detects key turning points of maturity in Croatian companies in a quantitative way and since it identifies more maturity components than earlier research (McCormack et al., 2009; Milanović et al., 2015). These new findings enrich the current body of knowledge on BPO and also provide practical implications that can be helpful for managers.

The paper is organized into five sections. After the introduction, BPO construct and BPO maturity model is presented. After that, the methodology of the survey conducted in Croatian companies is given. Results and fundamental discovery are described in the fourth chapter. Lastly, results are discussed and advice for new analysis are outlined.

**Maturity Model of Business Process Orientation**

BPO contains nine factors: Strategic perspective; Documentation of business processes; Process measurement; Process organizational structure; Employees management; Process culture; Market perspective; Supplier orientation; Computer technology (Škrinjar et al., 2010). These factors are more or less important depending on BPO maturity level.

The work in this paper was based on McCormack’s BPO maturity model (2001) which states that there are four stages in reaching BPO maturity.

The first stage is called **AdHoc level**, which indicates that processes in the company are ill-defined, business processes are not measured, organizational structures are functional, performance is not manageable and supplier and customer perspectives are poor.

The second maturity stage or the **Defined** level means that only basic work and business processes are described and registered and that customer satisfaction is higher than in the first stage, but still low when compared to competitors.

**Linked** level or the third maturity stage means that the structure of the company is more horizontally based and performance management is improved.

The fourth, highest maturity stage or the **Integrated** level, means that the organization works in cooperation with its clients and suppliers. Organizational structure is process-based, business processes are measured and managed on regular basis, the performance is extremely improved, costs are decreased and customer satisfaction turns into an advantage.
Methodology

Research instrument
The goal of the empirical research was to determine the BPO maturity level in Croatia and to detect key turning points for advancing to higher maturity levels. The initial version of the research instrument developed by McCormack and Johnson (2001) incorporated only 3 BPO factors and that is why the questionnaire in this research was enlarged. It contained 58 questions that were assigned across to 9 factors mentioned in the previous chapter. Every question represents an individual characteristic of process orientation that is specific for each factor. The extent of these characteristics in an organization was validated by 7 points Likert scale.

Data
The survey was sent to 1200 Croatian companies. 127 CEOs filled out the survey, so the response rate was 10.58%. Considering the total of employees, the final research set included 26% of big, 31% of middle-sized and 43% of small Croatian companies (Figure 1).

Figure 1
Frequency of companies

Source: Author’s calculation and illustration

Organizations from all sort of business are involved in the data sample. Financial and insurance services (16.53%) was the leading trade, followed by the Production (15.75%), Commerce (11.81%) and Information and communication services (11.09%). Other sorts of business represented 44.82% of the companies in the research.

Statistical methods
Before all, the questionnaire was checked for validity, using Cronbach’s alpha indicators. After that, the cluster analysis was used as an intent for detecting BPO levels of maturity. In the end, k-means clustering was conducted to detect maturity components for every BPO level.

Validity
First, exploratory factor analysis was carried out by applying SPSS 18.0. Factor Analysis Technique and the 0.5 cut-off loading value (Comrey & Lee, 1992) showed that the fourth question for Process organizational structure, the seventh questions for Process measurement and Process organizational structure, the sixth question for Business
process documentation, fifth and ninth questions for Strategic perspective have not hit the loading value and were consequently removed from analysis; (2) Ninth question for Employees management has also not reached the 0.50 value, but it was not removed from further analysis since it had very close value (0.495).

Table 1
Operationalization of BPO construct

<table>
<thead>
<tr>
<th>FACTORS</th>
<th>QUESTIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Strategic perspective</td>
<td>Process improvements are monitored by top management. Organizational strategy is the source for deriving process aims. Business process improvement is one of the main strategic goals. Policy and strategy are always explained to all employees. Business process improvement arises from customer needs and organizational strategy.</td>
</tr>
<tr>
<td>2. Documentation of business processes</td>
<td>In our organization business processes are identified and explained. Our organization documents core processes. Every process of responsibility is identified and documented. Most of the employees know how every process work. Models of business processes are available to everyone in the company. Business processes in our organization are analysed with methodology. Every business process has its process measures. If something changes in a business process it must be formally documented. Every stakeholder of our organization knows if something in core business process changes. Employees learn how to deal with new processes. Business process goals are the responsibility of the people in the organization.</td>
</tr>
<tr>
<td>3. Process measurement</td>
<td>Our organization measures business performance. Every business process has performance targets. Every process has its indicators of performance. Organizational goals are the base for process performance goals. Performance indicators are collected continuously. Performance indicators are always known. By analysing the results of the performance new performance aims are defined.</td>
</tr>
<tr>
<td>4. Process organizational structure</td>
<td>Business processes are executed throughout the organization. We have a team of employees from different units that work together. Employees are stimulated for their ideas and talents.</td>
</tr>
<tr>
<td>5. Employees management</td>
<td>Employees are held accountable for providing business process performance. Employees are trained to use IT systems.</td>
</tr>
<tr>
<td>6. Process culture</td>
<td>Executive managers regularly have consultations. Employees from separate organizational units consult each other.</td>
</tr>
<tr>
<td>7. Market perspective</td>
<td>Competition in our industry is monitored. Every action our competitor does reacts our side.</td>
</tr>
<tr>
<td>8. Supplier orientation</td>
<td>Our organization is partnering with our main dealers. Our organization collaborates with its key suppliers. If something changes in our business processes, we inform our suppliers about it.</td>
</tr>
<tr>
<td>9. Computer technology</td>
<td>Our organization is connected with its suppliers by different types of SCM. Our organization uses business process modelling tools. Our organization uses business process management tools. Business process management system is embedded in our company.</td>
</tr>
</tbody>
</table>

Source: Milanović Glavan et al. (2015)
The route of operationalization of the BPO construct done by McCormack and Johnson (2001) and Škrinjar and Trkman (2013) was followed and the cleared data were used to make the new BPO construct (Table 1). Operationalized BPO construct consists of the following factors: Process documentation; Process measurement; Computer technology; Strategic perspective; Process organizational structure; Supplier orientation; Employees management; Market perspective and Process culture.

New construct was then subjected to reliability analysis. All calculated values of Cronbach’s alpha coefficients outgrew the number 0.70 which represents the cut-off rate according to Feldt and Kim (2008). That means that item scales were consistent. Furthermore, the Comparative Fit Index was determined (0.906) and also, the Normed Fit Index was calculated (0.872). The Root Mean Square Error recorded a 0.080 value. Subsequently, it can be stated that this model satisfied all methodological imperatives.

**Results**

Primarily, the overall value of BPO in Croatian companies was examined and it scored 4.84. Then, by applying Statistical Package for Social Sciences TwoStep cluster analysis procedures were operated. The 127 sample cases were distributed into four different centroids, each representing one maturity level and maturity scores were identified (Figure 2).

With the 4.84 BPO value, Croatian companies fall in the middle of the Defined and Linked maturity stage. It means that their processes are defined, but business processes are not connected. Also, jobs and organizational structure have a process aspect but are still functional.

Finally, to identify key turning point k-means algorithm was used (Table 2). It is proposed that when the score at the centroid of each level goes above 50%, that factor is then established and it is regarded as a maturity component or key turning point (Vlahović et al., 2010). Table 2 shows all key turning points for all maturity levels. Turning points for proceeding to the "Defined" BPO maturity are: “Strategic perspective”, “Process documentation”, “Process measurement”, “Process organizational structure”, “Employees management”, “Process culture”, “Market
“Market perspective” and “Supplier orientation”. It can be seen that the leading factors for advancing to the Defined level are “Market perspective” and “Supplier orientation”. Key turning points for reaching the Linked BPO maturity include all factors, but the leading one is “Strategic perspective”. Advancing to the highest, integrated level of BPO maturity also involves all factors with a special emphasis on “Market perspective”.

Table 2
Maturity scores by domains

<table>
<thead>
<tr>
<th></th>
<th>AdHoc</th>
<th>Defined</th>
<th>Linked</th>
<th>Integrated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strategic perspective</td>
<td>52%</td>
<td>69%</td>
<td>83%</td>
<td>89%</td>
</tr>
<tr>
<td>Documentation of business processes</td>
<td>46%</td>
<td>63%</td>
<td>79%</td>
<td>91%</td>
</tr>
<tr>
<td>Process measurement</td>
<td>42%</td>
<td>60%</td>
<td>77%</td>
<td>91%</td>
</tr>
<tr>
<td>Process organizational structure</td>
<td>51%</td>
<td>70%</td>
<td>80%</td>
<td>90%</td>
</tr>
<tr>
<td>Employees management</td>
<td>42%</td>
<td>62%</td>
<td>72%</td>
<td>89%</td>
</tr>
<tr>
<td>Process culture</td>
<td>46%</td>
<td>58%</td>
<td>65%</td>
<td>75%</td>
</tr>
<tr>
<td>Market perspective</td>
<td>57%</td>
<td>71%</td>
<td>79%</td>
<td>91%</td>
</tr>
<tr>
<td>Supplier orientation</td>
<td>63%</td>
<td>71%</td>
<td>77%</td>
<td>85%</td>
</tr>
<tr>
<td>Computer technology</td>
<td>44%</td>
<td>47%</td>
<td>68%</td>
<td>80%</td>
</tr>
</tbody>
</table>

Source: Author’s calculation

Discussion and conclusion

Relations to previous findings and concluding remarks

Earlier research on BPO maturity levels in Croatia was conducted by using a decision tree model (Milanović Glavan et al., 2015). As stated in the introduction part of the paper the developed model detected few turning points. To identify more maturity components, cluster analysis approach was used, as it was recommended by McCormack et al. (2009). This approach has led to the discovery of 8 new maturity components that are necessary for advancing to the Defined BPO maturity and it included all 9 factors for advancing to Linked and Integrated maturity levels, which is in accordance to theoretical assumptions (McCormack et al., 2009). When advancing on Defined level emphasis must be on “Market perspective” and “Supplier orientation”. When reaching the Linked level of BPO maturity the leading component must be “Strategic perspective”. Advancing to the highest, integrated level of BPO maturity requests a special accent on “Market perspective” factor.

Practical implications

The findings of this paper can offer important implications for research and practice. These new findings enhance the field of BPO. The conducted research also provides practical implications since it can be helpful for leaders of Croatian companies. If wanting to reach the Defined maturity level Croatian managers have to increase the efforts in stimulating eight components of BPO and in nine of them if they want to advance to the third or fourth maturity level.

Research limitations and future studies

This research arises to several limitations. It must be pointed out that the study was done by using a questionnaire and that means concluding remarks can be subjective. The strength of cluster analysis methodology is in defining turning points. Nevertheless, sample size restrictions, need to be stressed out. Furthermore, the list of detected key turning points is valid only for Croatian companies.
The results of this article present support for further research. One way to raise the consistency of the research is to enlarge the number of companies that participated in this study. Also, the research was conducted only in Croatia and in the future, it can be done in other countries. Further investigation can also include a longitudinal study of maturity level changes in few companies.

References


About the author

Ljubica Milanović Glavan, PhD is an Assistant Professor. She teaches at the Faculty of Economics and Business, University of Zagreb, Department of Information Technology. She has received a PhD in Informatics with the dissertation thesis “Conceptual model of Process Performance Measurement System”. Her main research interests include business process management area and knowledge management, with a special emphasis on information technology. She is the author and co-author of many journal publications and she is engaged in numerous scientific projects. The author can be reached at ljmilanovic@efzg.hr