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Human-Centric Decision and Negotiation Support for Societal Transitions

Local Proceedings of the

24th International Conference on Group Decision and Negotiation &

10th International Conference on Decision Support System Technology

Vol I. Technology as a support tool

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Preface

The collection of papers results from the papers presented at the joint conference that gathered the 24th International Conference on Group Decision and Negotiation (GDN 2024) and the 10th International Conference on Decision Support System Technology (ICDSST 2024), held in Porto, Portugal, from 3–5 June, 2024. Both conferences were under the main theme "Human-centric decision and negotiation support for societal transitions". The event was organized by a local team from the Faculty of Engineering of the University of Porto, in collaboration with both the EURO Working Group on Decision Support Systems (EWG-DSS) and the Group Decision and Negotiation section from INFORMS.

This joint conference happened ten years after the last conference the two groups collaborated to organize, which was held in Toulouse, France, with a special focus: Group Decision Making and Web 3.0. That year marked the beginning of the ICDSST conferences. The EWG-DSS series of International Conferences on Decision Support System Technology (ICDSST) was planned to consolidate the tradition of annual events organized by the EWG-DSS in offering a platform for European and international DSS communities, comprising the academic and industrial sectors, to present state-of-the-art DSS research and developments, to discuss current challenges that surround decision-making processes, to exchange ideas about realistic and innovative solutions, and to co-develop potential business opportunities.

The GDN Section of INFORMS emerges from evolving, unifying approaches to group decision and negotiation processes. These processes are complex and self-organizing involving multiplayer, multicriteria, ill-structured, evolving, dynamic problems. In defining the domain of group decision and negotiation, the term "group" is interpreted to comprise all multiplayer contexts. Thus, organizational decision making support systems providing organization-wide support are included. Group decision and negotiation refers to the whole process or flow of activities relevant to group decision and negotiation, not only to the final choice itself, for example scanning, communication and information sharing, problem definition (representation) and evolution, alternative generation and social-emotional interaction. Descriptive, normative and design viewpoints are of interest. Thus, Group Decision and Negotiation deals broadly with relation and coordination in group processes.

Human-Centric Decision and Negotiation Support for Societal Transitions

The topic selected for the event reflected the interests of both groups and, as usual, the current world scene and research trends. In a time when technology is rapidly evolving, decision-makers face two major challenges: (1) using technology to improve the decision process, and (2) ensuring that decisions really support the best interests of the actors involved. On the one hand, the evolution of machine learning and AI offers incredible benefits; on the other hand, we as technology creators must ensure that humans remain the main beneficiaries of new services, software, and policies.
The transition period society is going through has brought even more complexity to decision processes, by increasing uncertainty regarding the future. Whatever is our research focus (climate, energy, AI, automation, information and communication technology, etc.), change, transition, and challenges are recurrent. Add uncertainty to the mix and we have highly complex decision processes, with several interested actors and multiple levels of goals. This recurring uncertainty has impacts on economics, employment, demographics, politics, and other societal concerns.

Accordingly, the topics promoted discussions on the human and technological aspects of decision-making processes to build bridges between two domains:

1. Technology as a support tool: from the technological perspective, research must demonstrate that technology can be trusted and that proposed solutions are safe, inclusive, and fair.

2. People as active participants: from the human perspective, research should ensure that humans remain at the center of the decisions, with participatory and negotiation processes that promote co-creation and co-design of technology, services, and regulations. Such reliable decision processes increase trust and fairness of decisions.

GDN Streams

1. Conflict Resolution

Strategic conflict arises whenever humans interact, individually or in groups. Recently-developed methodologies and techniques that can help analysts understand strategic conflicts and provide strategic support to negotiators have been of great benefit to decision makers. New theoretical issues are now being explored, and at the same time new software systems are making modeling easier and analytical results clearer. Both theoretical and practical approaches have been used to study strategic conflicts in diverse areas including environmental management, global warming, energy, the food crisis, economic disparities, international trade and aging infrastructure.
The main objective of the Stream on Conflict Resolution is to provide a forum for discussion of recent advances in the development of formal conflict resolution techniques and their insightful application across a range of domains.

Stream organizers
Liping Fang, Toronto Metropolitan University, Toronto, Canada
Keith W. Hipel, University of Waterloo, Waterloo, Canada
Marc Kilgour, Wilfrid Laurier University, Waterloo, Canada

2. Negotiation Support Systems and Studies (NS3)

Electronic negotiations are nowadays common business practice. Dedicated electronic negotiation support systems (NSSs) enable complex, asynchronous, and dislocated negotiations.
NS3 Stream presents papers that (1) help bridging the gap between the vast amount of work on face-to-face negotiations and electronic negotiations as well as decision and negotiation aids embedded in negotiation processes; (2) that focus on the design and use of tools for decision support, communication support, document management, or conflict management for the negotiators and mediators in electronic negotiation processes

Stream organizers
Mareike Schoop, University of Hohenheim, Germany
Rudolf Vetschera, University of Vienna, Austria
Muhammed-Fatih Kaya, University of Hohenheim, Germany

3. Preference Modeling for Group Decision and Negotiation

A variety of methods, techniques, and normative models, mainly derived from multiple criteria decision making (MCDM) and game theory, may be used to support groups of negotiators and decision makers (DM) in defining their goals, eliciting preferences, and building the negotiation offers' scoring systems. The latter is fundamental for providing the groups with reliable decision support throughout the entire negotiation or group decision making process. However, many factors, such as cognitive issues, formal knowledge, and DM skills, may influence the actual use of scoring systems. Therefore, there is a constant need for redesigning the existing methods and designing new ones that allow for accurate preference modeling and elicitation for group decision and negotiation (GDN) process in a particular decision-making context, given the DMs' limitations regarding information processing and all formal and behavioral issues involved.
The main goal of this stream is to create a forum for scientists, researchers, and practitioners working on the topic of preference modeling for GDN that will allow them to exchange their experience and knowledge and discuss the recent developments and results of their research.

Stream organizers
Danielle Morais, Federal University of Pernambuco, Brazil
Tomasz Wachowicz, University of Economics in Katowice, Poland

4. Collaborative Decision Making

Making a decision for a group engaged in a common task is a difficult challenge. There are several kinds of group decision making processes. This stream addresses Collaborative Decision Making processes. By Collaborative Decision Making processes, we intend that involved participants must pool their efforts in order to define and work on the achievement of a common goal. They have to integrate multiple points of view which reveal to be difficult. They have to work together, although not necessarily in the same place or at the same time. Decisional processes are then complex and involve a non-closed set of actors. The difficult point for decision-makers is to make a balance between their own preferences and the building of common preferences within the group. One direct application in the daily life of such Collaborative Decision-Making processes can be implemented through the e_democraty which is defined as a form of government in which all adult citizens are presumed to be eligible to participate equally in the proposal, development, and creation of laws.
The purpose of this stream is to allow researchers to present methodologies, mathematical models, and software supporting Collaborative Decision-Making processes.

Stream organizers
Pascale Zaraté, Toulouse Capitole University, IRIT, France
Guy Camilleri, Toulouse 3 University, IRIT, France

5. Network Analysis of Decisions in Groups

We consider the topics related to the interaction among participants in groups, and try to reveal key players in such situations. The stream studies international conflicts, terrorist activity, decisions during pandemics, the problems of food security, migration of people because of tensions in the Middle East, etc., but not only these topics.
The session includes the papers that contain recent results obtained by research teams from academia and industry.

Stream organizers
Fuad Aleskerov, Professor, HSE University, Moscow, Russia
Alexey Myachin, Professor, HSE University, Moscow, Russia

6. Responsible NSS in the age of Generative AI

The ubiquitous growth of generative AI has generated highly intelligent and effective applications in virtually every aspect of human activities, including support for individual or institutional decision-making and negotiation. At the same time, AI-based applications have raised a global concern about its unintended consequences. Researchers and administrators in virtually all academic disciplines and practitioners' circles are debating on the future of generative AI in their respective field. This paper stream addresses the opportunities and limitations, concerns and risk of adopting generative AI – defined in its broadest sense – in the context of group decision and negotiation.

Stream organizers
Tung Bui, Matson Navigation Co. Professor
Shidler College of Business, University of Hawaii, Honolulu, USA

7. Risk evaluation and negotiation strategies

The complex process of determining the value of the identified hazards and estimated risks to those affected is often needed to model and analyze in practice. Negotiation strategies arises when conflicts have happened. The main goal of the Stream of Risk Evaluation and Negotiation Strategies is to discuss the current theories and applications and explore the future development related the stream.

Stream organizers
Haiyan Xu, Nanjing University of Aeronautics and Astronautics, China
Shawei He, Nanjing University of Aeronautics and Astronautics, China
Shinan Zhao, Jiangsu University of Science and Technology, China

Keynote speakers

Argumentation-based Deliberation: Foundations and Challenges, by Leila Amgoud

Recognized as vital in a group decision-making process, deliberation allows stakeholders discussing and reaching agreements on controversial issues before making ultimate decisions. It brings several benefits, one of which is ensuring well-informed and well-accepted decisions. Its backbone is argumentation, which consists of justifying claims by arguments, i.e., reasons behind claims. The greatest challenges facing deliberation systems are identifying, evaluating, and aggregating large sets of interacting arguments, generally of disparate types, and solving potential disagreements between stakeholders. In this talk, I will introduce abstract argumentation frameworks for deliberation, their formal foundations, and discuss their possible impacts on group decisions.

Leila Amgoud is a senior researcher at the French National Centre for Scientific Research (CNRS), a member of the IRIT Lab in Toulouse, and a deputy director of the same lab. She holds a M.Sc. (1996), a PhD (1999) and an Habilitation à Diriger des Recherches (2009) in Computer Science from the Paul Sabatier University, Toulouse, France. She is currently an Associate Editor of the Artificial Intelligence Journal and the Journal of Argument and Computation. She has been an EurAI Fellow since 2014. Her research interests are centered around knowledge representation and reasoning. She is specifically interested in argumentation-based approaches for reasoning and decision making under uncertainty, and more recently in explainability of AI models. She holds two chairs on "explainability" and "argumentation-based deliberation" at the interdisciplinary Artificial and Natural Intelligence Toulouse Institute (ANITI).

Supporting Advanced Analytics Practice with Gen AI, by Pedro Amorim

The generative AI hype, with all its glare, is overshadowing advanced analytics, which is a more straightforward approach to delivering value to businesses by improving decision-making (e.g., pricing, assortment, or distribution decisions). In this presentation, we'll discuss how companies should refocus on improving decision-making using advanced analytics, such as predictive and prescriptive approaches, while acknowledging the extra effectiveness and efficiency that generative AI may deliver to this endeavor. This path requires us to go beyond buzzwords and understand the technical complementariness of the different technologies.

Pedro Amorim is a seasoned professional bridging the realms of academia and analytics. Holding a Certified Analytics Professional and a Ph.D. in Industrial Engineering and Management, he boasts over a decade of hands-on experience leading analytics projects. Pedro is a Professor at the Faculty of Engineering of the University of Porto and Porto Business School, and he is a Co-founder and partner at LTPlabs. His multifaceted expertise underscores his commitment to advancing the field, both through practical applications and academic mentorship.

A GDN Odyssey, by Daniel Druckman

In this keynote address I take the audience on a journey through 27 years of publishing articles in GDN. My first article appeared in a 1997 special issue on "The Logic of Comparative Negotiation Analysis." This was an analysis in search of key dimensions of international negotiation. It was followed in 1999 by an article that honed in on Fred Ikle's taxonomy of negotiation, producing strong empirical support for his theory and a gracious thank you letter from Fred. The first of many articles on automated mediation began with a 2002 article that described the Negotiator Assistant system. This was followed in 2004 and then in 2014 by ambitious experimental evaluations of screen vs. human mediation. This stream culminated in our 2021awared winning article on robot meditation. The upshot is that robots produced more and better agreements than any of the other formats.

A slight detour from technical articles to the role of emotions resulted in a highly cited special issue that showed the many ways that emotions influence negotiation. Nine years later we produced another special issue on justice and fairness with a mix of quantitative and qualitative articles in a variety of settings. About that time I was working on positive affirmation as a technique for improving the chances of getting better agreements (2019) and on how negotiators react to turning points with matching or mismatching strategies. Most recently, in 2022, we answered the question: Does trust matter in negotiation? The answer is an emphatic yes.

This GDN journey spanned topics at the center of our field, from types of international negotiations to the importance of trust in any negotiation. The key insights that emerged reinforce our claims about the value of doing systematic research

with practical implications. In summing up, I will try to push the field further in directions that broaden our understanding of these processes and contexts as well as strengthen GDN's contribution to the social and informational sciences.

Daniel Druckman is Professor Emeritus of Public and International Affairs at George Mason's Schar School of Policy and Government and an Honorary Professor at Macquarie University in Sydney and at the University of Queensland in Brisbane Australia. Two of his books, Doing Research: Methods of Inquiry for Conflict Analysis (Sage, 2005) and, with Paul F. Diehl, Evaluating Peace Operations (Lynne Reinner, 2010) received the outstanding book award from the International Association for Conflict Management (IACM). His co-authored article on robot mediation (2021) received a best article of the year award from GDN. He also received lifetime achievement and Rubin Theory to Practice awards from the IACM in 2003 and 2018 respectively. He also received lifetime achievement awards from the Novancia Business School in Paris in 2016 and from the Schar School of Policy and Government in 2023.

Round table

A round table was held under the conference's main theme *Human-Centric Decision and Negotiation Support for Societal Transitions.*
While technology allows us to make better and fast decisions, societal changes need the active participation from people. On the one hand, society is fast changing, on the other hand, the solution to a sustainable world seems to be a slow life style. Population growth demands for more resources, but there not enough resources. Policymakers must decide fast, still decisions must be based on real information.
There is no doubt we need technology. There is no doubt technology improves our lives.
There are some doubts on how much technology we need. There are some doubts on

The round table addresses the questions:
Are "human-centric" decisions really centered on humans? Are algorithms supporting our decisions or silently choosing on our behalf?

Moderated by Sérgio Pedro Duarte with the participation of:

- Fátima Dargam (EWG-DSS)
- Liping Fang (GDN Section)
- Isabel Paiva de Sousa (Porto Business School)

Doctoral Consortium

This event provides an opportunity for graduate students to explore their research interests in an interdisciplinary workshop under the guidance of a panel of distinguished experts in the field. During the DC, students present their research work in a relaxed and supportive environment, receive feedback and suggestions from experienced faculty members, discuss concerns about research, and network with faculty, peers, and future colleagues.

Doctoral Consortium Committee

Liping Fang (Chair), Toronto Metropolitan University, Canada
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Decision Support Systems Technology

Conference papers

24th International Conference on Group Decision and Negotiation &
10th International Conference on Decision Support System Technology
Human-Centric Decision and Negotiation Support for Societal Transitions

Combining LLM and DIDEX method to predict Internal Migrations in Serbia

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Abstract

In this study, we explore the integration of vast knowledge from large language models to enhance the data-induced decision expert (DEX) model's ability to understand and forecast internal migrations in Serbia. We combine LLMs with Decision Support Systems (DSS), specifically focusing on data-induced decision expert (DIDEX) methodology, to significantly improve attribute selection, and model interpretation, which is vital for making informed decisions. The fundamental idea of this paper involves utilizing LLMs to define a hierarchy of attributes and using DIDEX on data utilizing those attributes to generate the necessary decision rules for the DEX model. The proposed DSS is enabling policymakers in evaluating the impact of various potential municipal interventions for sustainable internal migrations across Serbian local self governments. A comparative analysis of traditional machine learning models and DIDEX was performed, utilizing both GPT 3.5 Turbo and GPT 4 Turbo. The findings indicate that LLMs achieve results comparable to machine learning models while inheriting the advantages of DEX models. More specifically, classification accuracy is around 64%, while the DIDEX model achieves 65%. While the time needed to create a DIDEX model reduced significantly by using LLMs the interpretation of the obtained DEX model was highly increased.

Keywords: Decision EXpert; Data-Induced DEX; LLM; Internal Migrations; DSS

1. Introduction

This study focuses on proposing a combination of large language models (LLMs) and data-induced decision expert models (DIDEX) to create a data-and-expert-aware decision support system (DSS) to assist in formulating policies for internal migration management, utilizing actual population statistics, other economic and social data sources, and LLMs. The main reason for such a DSS is the fact that a thorough comprehension of migration dynamics is essential for crafting effective policies. However, the quality and accessibility of the necessary data are often compromised, marked by gaps, outdatedness, or inconsistencies (Soofi & Awan, 2017). This data inadequacy poses a challenge for machine learning (ML) models, which may yield biased outcomes due to flawed data assumptions.

To mitigate these issues, our approach involves synthesizing new attributes from the existing data, thereby enhancing the model's reliability. The proposed combination of LLMs and DSS aims at harnessing the knowledge stored in the large language models and algorithmic discovery of knowledge from data rather than manual construction. The main motivation for such an approach is the downside of traditional ML models, where DSSs prioritize transparency, accuracy, consistency, and real-world applicability in policy decision-making (Bohanec, 2021). A critical aspect of the DSS is ensuring a monotonic relationship between inputs and outputs, a feature often missing in conventional ML algorithms. This means that any modification in the input should lead to a predictable and consistent response in the output, a vital characteristic for policy-related decisions.

Our paper integrates LLMs with DSS, more specifically DEX (Bohanec, 2022) and DIDEX (Radovanović, et al., 2023a) method. This combination greatly enhances data interpretation capabilities, a critical aspect in making informed decisions. In other words, LLMs provide DIDEX contextual understanding and sentiment analysis of vast and varied data sets used for the LLM training. LLMs excel in processing and understanding large volumes of unstructured data – such as textual content and complex reports – which are often challenging for traditional DSS to analyze effectively (i.e., requires a huge experience from the human decision maker). This capability allows the DSS to extract meaningful insights from a wider range of sources, providing a more comprehensive view of the subject matter.

Incorporating LLMs into DIDEX transforms the way data is interpreted, moving beyond mere numerical analytics to a more sophisticated understanding of complex, nuanced, and often qualitative information. The core idea is to use LLMs to derive an attribute hierarchy and then use DIDEX to derive tables of decision rules that are needed for DEX to make decisions. This integration paves the way for more informed, context-aware, and empathetic decision-making processes in various sectors.

The remainder of the paper is structured as follows: Section 2 explains the Materials and Methods. More specifically, we describe the data used for this paper, combination of LLMs and DIDEX, and describe the experimental setup. Section 3 provides the newly obtained models, while Section 4 provides the results and the discussion. Finally, Section 5 concludes the paper and provides the future research directions.

2. Materials and Methods

This section explains the data used in this research, as well as the procedure how large language models is used to enhance DIDEX algorithm. The final part of this section is experimental setup used in this research.

2.1. Data

In the development of the DEX and DIDEX models, comprehensive data acquisition and integration were key steps. Data was sourced from a variety of reputable institutions in Serbia, including the Open Data portal of the Statistical Office of the Republic of Serbia, the Statistical Office's yearbooks, the Serbian Business Registers Agency, the Social Inclusion and Poverty Reduction Unit, and the Public Policy Secretariat of the Government of the Republic of Serbia. To enhance the dataset, we incorporated geographic information through the Google Maps Distance API and Open Street Maps Overpass Turbo API, enabling the calculation of accessibility to various resources.

The data preprocessing involved an intricate process of merging these diverse datasets to represent the condition of each Serbian municipality in a given year. The time frame for the data spanned from 2011 to 2022, covering all municipalities except for Kosovo and Metohija, leading to a comprehensive dataset with 742 attributes. The data is prepared in the same manner as in the (Delibašić et al., 2023) regarding the data extraction, data preparation, and experiment setup.

For our analysis, we focused on predicting internal net migration per 1,000 inhabitants as the key label attribute. This measure, aligning with *Aggregate Crude Migration Intensity* as defined in (Bell et al. 2015), calculates the migration balance within a municipality, adjusted for population size and normalized per 1,000 inhabitants. Importantly, net migrations are considered for the subsequent year, reflecting the premise that policy interventions are unlikely to have immediate effects.

Observational data indicates that during the studied period, Serbia experienced a stable net migration rate, albeit with a slight emigration trend at -2‰. Notably, certain municipalities, including Belgrade, Novi Sad, and Niš, emerged as regional hubs with net immigration patterns. The primary objective of our research is to ascertain whether a model can be developed that effectively predicts internal migration patterns, adhering to the essential decision support system qualities of comprehensiveness and user convenience, which are crucial for policymakers.

2.2. LLM-based DIDEX

The DEX methodology, initially introduced by (Bohanec & Rajković, 1990), has long been recognized for its expert-driven feature engineering and modelling. This approach is lauded for the interpretability and explanatory power it brings to decision models, ensuring that the decision rules integrated within DEX models are complete and consistent. In DEX models, feature engineering is conducted from the bottom up, systematically chaining attribute interactions into decision rules that culminate in a comprehensive decision tree. In a significant advancement, (Radovanović et al., 2023a), proposed the DIDEX method, which automates the development of DEX models from data. DIDEX maintains the predictive accuracy comparable to complex ML models while retaining the beneficial attributes of DEX models. This method involves generating DEX models with an inherent hierarchy and decision rules directly from the data, employing a bottom-up iterative approach. Initially, flat DEX models are formulated, which are then refined through the input of domain experts. This process involves shaping a hierarchy of attributes and rules to meet critical criteria such as correctness, completeness, consistency, comprehensibility, and user convenience. DIDEX balances the complexity of the model – considering both the depth of the hierarchy and the number of decision rules – against its accuracy, as judged by predictive reliability and the empirical support of the decision rules in the data. The iterative process continues until a deterioration in the Bayesian Information Criterion is achieved.

This paper introduces a novel concept: the integration of LLMs with the DIDEX method, resulting in an enhanced DIDEX model. The aim is to leverage the extensive knowledge encapsulated in modern LLMs to refine the DIDEX procedure. This involves utilizing LLMs to extract and learn concepts based on the available data, thereby enriching the DIDEX process with deeper, data-driven insights.

The challenges encountered in the DIDEX procedure can be broadly categorized into two primary groups. The first pertains to the process of attribute grouping in environments with high-dimensional data, where the sheer number of attributes leads to significant computational demands. The task involves generating and appraising all potential combinations of two and three attributes for their interactions. Despite being resource-intensive, this comprehensive evaluation is crucial for enhancing the accuracy of the final model. (Radovanović et al., 2023a) framed this selection process as a decision-making problem, where the optimal interaction is determined based on a weighted sum of four key criteria: the depth of the hierarchy, the number of decision rules, the empirical support for each rule in the dataset, and the accuracy of these rules. This procedure of creating and assessing interactions is recursively implemented until the label attribute is identified, which marks the completion of the process. This leads to the second set of issues – the ambiguity in the significance of the newly formulated concepts. There are instances where DIDEX may combine attributes that are ostensibly unrelated or dissimilar, leading to skepticism among human experts regarding the methodology's effectiveness. This is where LLMs can play a transformative role. By leveraging the extensive knowledge embedded within LLMs, they can aid in proposing a more coherent and logical hierarchy for attribute grouping. The integration of LLMs in this context is intended to assist in the initial structuring of attributes, while the DIDEX system focuses on the computation of decision tables for these newly formed attribute groups. This synergistic approach aims to address both the computational challenges and the conceptual clarity of the DIDEX procedure. It is worth stating that human decision-maker is in the loop. The set of input attributes and the definition of the output attribute is done by the human decision maker in collaboration with the decision analyst. Later, after the integration of the LLMs human decision maker validates the model providing some notion of the reliability of the model.

2.3. Experimental Setup

In addressing our research question, we narrowed our focus to a set of nine chosen attributes: *Motorcycle Density*, *Doctors Accessibility*, *Vehicles Density*, *Primary School Attendance*, *Secondary School Attendance*, *Assistance and Care Allowance Share*, *Poverty Share*, *Local Roads Density*, and *Main Roads Accessibility*. These attributes were selected by data modelers and domain experts to effectively encapsulate key aspects of municipal functioning, encompassing areas like transportation infrastructure, resource accessibility, education, healthcare, and economic growth.

Our methodology involved a year-wise validation procedure for testing various algorithms. In this approach, the model is trained on data from a specific year and its performance is evaluated on the subsequent year. We calculated the average classification accuracy along with its standard deviation, applying this method to several algorithms, namely Decision Tree, Random Forest, and Gradient Boosted Tree. These were chosen for their commonality in decision tree-based methods, and their results were compared with the plain DIDEX algorithm (Radovanović et al., 2023b), a bottom-up induced tree represented in Figure 1. It is worth noting that DEX methodology requires categorical inputs. Thus, we performed equal size binning procedure for DEX models. This is recommended by (Radovanović et al., 2023a) so every bin has equal support in data. For the ML algorithms we provide two sets of results – one with the same binning aiming to discuss if the binning procedure could be improved and one with the original representation of data.

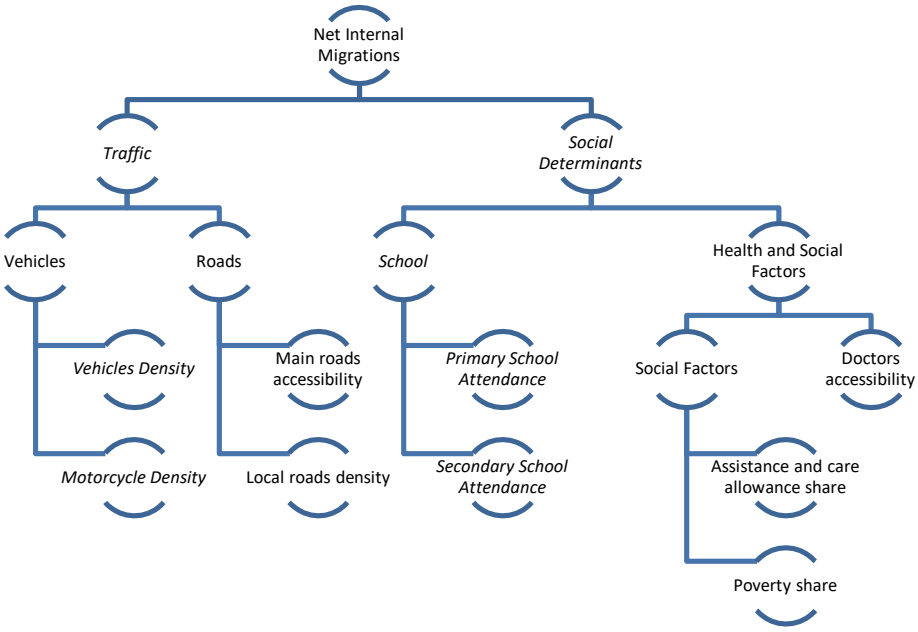

Figure 1. Original DIDEX model

Furthermore, we incorporated two versions of LLMs developed by OpenAI: GPT 3.5 Turbo (Ye et al., 2023), and the more recent GPT 4 Turbo (Chang, 2023). Both models are renowned for their efficiency and efficacy in natural language processing, with GPT 4 Turbo notably excelling in generating and understanding complex, nuanced text and handling tasks with enhanced contextual awareness. Our experimental setup with these LLMs required establishing a specific communication context and formulating appropriate queries.

```
context = "You are a helpful assistant who understands factors of internal migrations. You should merge attributes that are related to each other into factors and name them. Always return the output as JSON file where the first element is Concept Name, second element Concept Description, and the third element a list of attributes"


query = f"I have to predict {df.columns[-1]} based on the {', '.join(df.columns[:-1].to_list())}. Please provide me a hierarchy of concepts"
```

3. Results

This section provides the results of the GPT enhanced DIDEX models. We first describe the obtained models, and later compare the results with the best DIDEX model obtained for the problem at hand, as well as with the state-of-the-art machine learning models for tabular data.

3.1. GPT 3.5 Turbo DIDEX Model

The GPT 3.5 Turbo resulted in the model having only six elementary attributes. Namely, *Motorcycle Density*, *Vehicles Density*, *Poverty Share*, *Doctors Accessibility*, *Primary School Attendance*, and *Secondary School Attendance*. These attributes are grouped into a hierarchy of three levels where the second level consists of *Socio-Economic Development Factor* and *Educational Accessibility Factor*. What is interesting to note is that road accessibility is not considered as important by this model. More specifically, the knowledge inside the GPT 3.5 turbo indicates that motorcycle and vehicle density contain the economic dimension of the municipality. The obtained hierarchy is presented in Figure 2.

The *Socio-Economic Development Factor* represents the overall level of socio-economic development in a municipality. It combines factors such as the availability of transportation (motorcycle and vehicles density) and the poverty share, which reflects the economic conditions of the population. The DIDEX part of the algorithm helped us derive the decision table that makes the *Motorcycle Density* as the most important attribute with 53% of the importance, followed by *Vehicles Density* with 42% of importance. Finally, *Poverty Share* is almost irrelevant with 5% of importance.

On the other hand, *Educational Accessibility Factor* combines *Doctors Accessibility*, *Primary School Attendance*, and *Secondary School Attendance*. This factor represents the accessibility and quality of education in a region. Interestingly, the most important attribute is *Primary School Attendance* with 56%, followed by *Secondary School Attendance* with 31%, and *Doctors Accessibility* weights 12%.

Finally, the label attribute (net migrations per 1,000 inhabitants) is concluded with the decision table stating that *Socio-Economic Development Factor* is a bit more important than *Educational Accessibility Factor* with 60% importance compared to 40%. It is interesting to note that the only rule leading to positive net migrations is when both *Socio-Economic Development Factor* and *Educational Accessibility Factor* are having good value. On the other side of the spectrum, if *Socio-Economic Development Factor* of a municipality is poor, internal migrations will be poor as well, regardless of the *Educational Accessibility Factor*. Also, good value of *Socio-Economic Development Factor* but combined with poor *Educational Accessibility Factor* will lead to poor internal migrations.

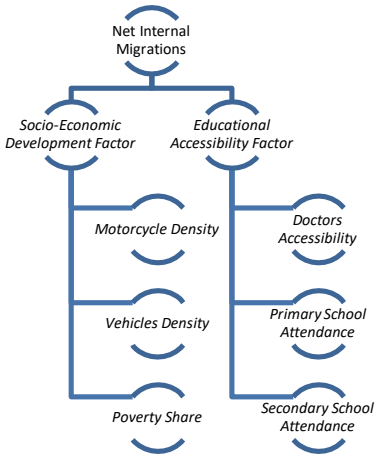

Figure 2. GPT 3.5 Turbo enhanced DIDEX

3.2. GPT 4 Turbo DIDEX Model

Compared to the previous model, GPT 4 Turbo made use of seven elementary attributes and combined them differently into a hierarchy. Elementary attributes are, namely, *Motorcycle Density*, *Vehicles Density*, *Local Roads Density*, *Primary School Attendance*, *Secondary School Attendance, Doctors Accessibility*, and *Assistance and Care Allowance Share*. These attributes are grouped into a hierarchy of three levels where the second level consists of *Transportation Infrastructure Factor, Educational Access Factor,* and *Healthcare Accessibility Factor*. The model is presented in Figure 3.

The *Transportation Infrastructure Factor* reflects the quality and availability of transportation options within an area, which can impact an individual's ability to commute and access various opportunities. It combines factors such as the availability of transportation (motorcycle and vehicles density) and local road density. Again, the *Motorcycle Density* is the most important attribute with 50% of the importance, followed by *Vehicles Density* with 36% of importance, and finally, *Local Roads Density* has 14% of importance.

Educational Access Factor combines *Primary School Attendance* and *Secondary School Attendance*. This factor reflects the quality and availability of transportation options within an area, which can impact an individual's ability to commute and access various opportunities. Interestingly, the most important attribute is *Secondary School Attendance* with 60%, while *Primary School Attendance* has 40% importance.

The third derived concept is *Healthcare Accessibility Factor* and it consists of *Doctors Accessibility* and *Assistance and Care Allowance Share*. This factor represents the availability of healthcare services and the level of support for individuals needing assistance and care, influencing migration decisions especially for individuals with healthcare needs. When we combine these two factors, we obtain that dominant attribute is *Assistance and Care Allowance Share* with 100% of importance. This is due to the lack of knowledge about the data at hand from the large language model.

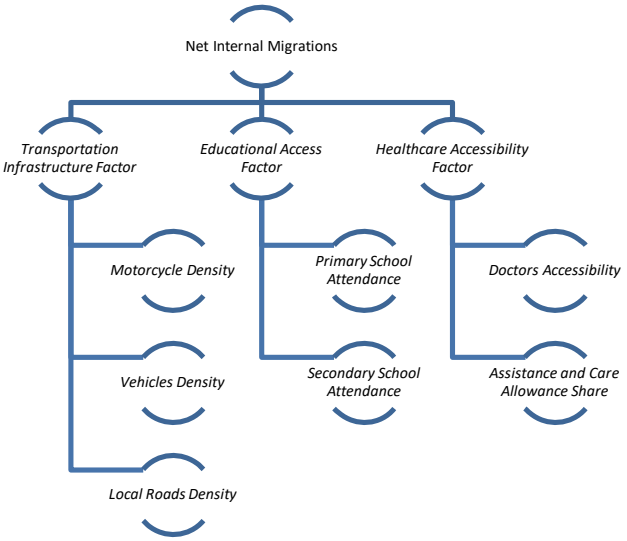

Figure 3. GPT 4 Turbo enhanced DIDEX

Finally, the net migrations per 1,000 inhabitants attribute is concluded with the decision table stating that *Transportation Infrastructure Factor* is the most important attribute with 50%. However, *Educational Access Factor* influences the decision with 43%. Finally, *Healthcare Accessibility Factor* has 7% of importance.

3.3. Results and Discussion

After running the experiments, we obtained following results as presented in Table 1. The *GPT 3.5 Turbo DIDEX Model* demonstrated a decline in performance, primarily attributed to its subpar classification accuracy of 56.89% in the initial year (test year 2012). This shortfall significantly impacted the model's

overall average classification score and led to an increased variability in the results. Despite this, the model showed signs of comparability in subsequent years, with the 2014 score exceeding 70%. In contrast, the *GPT 4 Turbo DIDEX Model* maintained a more consistent performance, not dropping below 60% in classification accuracy in any single year. While it showed slight improvement over the *GPT 3.5 Turbo DIDEX Model*, it still lagged behind the original DIDEX model in terms of classification accuracy.

Table 1. Classification Accuracy performance

Group	Model	Accuracy
DEX	DIDEX	65.18% ± 2.58%
DEX	GPT 3.5 Turbo DIDEX Model	63.11% ± 4.82%
DEX	GPT 4 Turbo DIDEX Model	63.82% ± 2.03%
ML	Random Forest	68.59% ± 2.56%
ML	Gradient Boosted Trees	71.72% ± 3.20%
ML	Decision Tree	63.78% ± 2.74%
ML	Random Forest (original values)	69.98% ± 4.27%
ML	Gradient Boosted Trees (original values)	72.87% ± 3.24%
ML	Decision Tree (original values)	64.92% ± 3.35%

The DIDEX model outperformed the GPT enhanced DIDEX models, with the GPT-enhanced versions exhibiting a reduction in classification accuracy of approximately 2% on average. However, a significant advantage of the GPT models lies in their markedly reduced training times. The DIDEX procedure, known for its time-intensive nature requiring several minutes per model, is considerably faster with GPT, which can learn a model in seconds. This rapid learning rate is especially noteworthy for models with a limited number of attributes, like the nine-attribute models we tested, outpacing even ML-based models in speed. However, it's important to note that GPT's efficacy in processing and structuring a small number of attributes may not extend as effectively to high-dimensional problems.

When compared with traditional ML algorithms, the DIDEX-based models showed comparable results to the *Decision Tree* algorithm but fell short against the more robust *Random Forest* and *Gradient Boosted Trees*. These ensemble algorithms leverage their ability to create multiple models and aggregate results, leading to superior performance.

A crucial observation was made when utilizing the original, non-discretized data: the classification accuracy for ML algorithms improved, suggesting that the discretization process in DIDEX potentially leads to information loss. This highlights an area for enhancement within the DIDEX algorithm, specifically in its approach to data discretization.

4. Conclusions

Our study presents an innovative integration of LLMs with DSS, specifically focusing on DEX method. This integration significantly enhances the DSS's ability to interpret data, as LLMs provide nuanced contextual understanding. The DIDEX procedure faces two main challenges: the computationally intensive task of evaluating attribute interactions in high-dimensional data, and the ambiguity in the significance of newly formulated concepts when combining seemingly unrelated attributes. Leveraging LLMs offers a solution by providing a coherent hierarchy for attribute grouping, thus addressing both the computational and conceptual clarity issues in the DIDEX process.

In our research, we developed LLM enhanced DIDEX models using data from Serbian institutions to predict internal migration, finding that while DIDEX outperformed GPT-enhanced models in accuracy. However, GPT models significantly reduced training time. Compared to traditional machine learning algorithms, DIDEX-based models were on par with Decision Trees but less effective than ensemble methods like Random Forest and Gradient Boosted Trees, which benefit from aggregating multiple models for improved performance.

The main benefits of using LLMs for DEX model learning lies in the enhancement data interpretation. LLMs have the capability to process and interpret extensive volumes of unstructured data, mainly text and reports. These types of data are typically challenging for traditional DSS to manage, thus enabling them to understand context and nuances in the data, making them exceptionally useful for comprehensive data analysis. The integration of DIDEX with the text understanding and generation capabilities of LLMs creates a powerful analytical tool. The combined system can not only predict the outcome one seeks but also articulate the model in clear, understandable language. In addition, the process of the model learning is significantly lower compared to the original DIDEX model.

LLMs, while extraordinary in their capabilities, are not without issues. One significant concern is their potential to perpetuate and amplify biases present in the data they were trained on (Zhang et al., 2023). This can lead to biased or insensitive responses, particularly in handling sensitive topics or minority perspectives. Another challenge is the accuracy of information; LLMs may generate plausible-sounding but factually incorrect or misleading content, making it crucial for users to verify information independently (Hadi et al., 2023). A big caveat surrounding LLMs is in understanding the reasoning behind their responses that can be difficult, which poses challenges in high-stakes decision-making scenarios.

Having the obtained results in mind, we will seek different strategies for data discretization such as using joint discretization that will ensure approximately equal support of every decision rule in the dataset. This will help making the DIDEX more reliable. In addition, we would like to make LLM-based models more reliable by utilizing *langchain*-like procedure (Lewis et al., 2020).

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Human-Centric Decision and Negotiation Support for Societal Transitions

Towards Certification of Sustainable Mobility: A Qualitative Multi-Criteria Modelling Approach

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Abstract

The concept of sustainable mobility is aimed at minimising environmental impacts of transportation systems while meeting the needs of individuals and communities. This includes encouraging citizens to choosing sustainable modes of transportation: walking, cycling, public transport, carpooling, and telecommuting. We present an ongoing attempt at rewarding organisations that actively support the sustainable mobility of their employees. We propose a sustainable mobility certificate, which can be received by organisations that fulfil sustainable mobility goals and objectives. The assessment is carried out using a qualitative rule-based multi-criteria model, which considers 50 sustainable mobility indicators. Other elements of the certification process include methods for assessing the mobility structure of employees in the organisation and its potential for improvement. In this paper, we present the multi-criteria evaluation model and illustrate its application for assessing the status of sustainable mobility of employees at a Slovenian research institute.

Keywords: sustainable mobility; mobility certificate; SmartMOVE project; multi-criteria model; method DEX

1. Introduction

The mobility of people and goods is one of the cornerstones of modern society. However, ever increasing traffic causes various adverse effects on individuals, communities and the environment: congestion, air and noise pollution, infrastructure strain, social isolation and inequality, economic costs and others (Bıyık, et al., 2021).

Ljubljana, the capital city of Slovenia, is no exception. With approximately 300,000 inhabitants, Ljubljana is one of the smallest European capital cities. Nevertheless, it is faced with severe traffic problems. There are over 220,000 jobs in the city, which account for over 25% of all jobs in Slovenia. As a result, over 120,000 people commute to Ljubljana daily from elsewhere. This means approximately 100,000 vehicles entering and exiting Ljubljana on a daily basis. The majority of those are private cars; the estimated average occupancy is 1.2 persons per vehicle. Thus, it is essential to employ the concepts of sustainable mobility (Gallo and Marinelli, 2020; Morfoulaki and Papathanasiou, 2021), particularly to reduce the number of cars in favour of public transportation and other more sustainable means of transportation, such as walking, cycling and car sharing.

SmartMOVE[1] is an ongoing project aimed at the preparation of strategies and mobility plans, in order to justify the need for systematic development of sustainable mobility in the Ljubljana Urban Region. The main

[1] https://www.smart-move.si/en/

goal is to limit the negative environmental impacts resulting from unsustainable forms of mobility and the long-term development of sustainable mobility. Several novel approaches have been or are being proposed and assessed. One of them is a system of dynamic on-demand collective passenger transport as a sustainable alternative to the existing transport modalities (Bohanec, et al., 2023). Others include the development of mobility plans for large organisations that are located on main mobility hubs, such as the University Medical Centre and Business Trade Center. Specific policy recommendations for decision-makers in the field of sustainable mobility are also being prepared.

In this paper, we address another ongoing SmartMOVE activity: development of a *certificate* for organisations that take good care of *sustainable mobility* of their *employees*. The idea is that a company that monitors, actively supports, evaluates and, in the long term, improves the mobility of their employees towards sustainability is encouraged and awarded by an officially and publicly recognised certificate, which may, in perspective, bring advantages to such companies, e.g., in obtaining governmental projects and funds.

The central component of the analytical process as part of the certification consists of *a multi-criteria evaluation model* that prescribes the necessary conditions and evaluation criteria for awarding the certificate. The model considers 50 indicators, with which it assesses important aspects of sustainable mobility, including the current situation in the organisation, its vision and management, performance in terms of general and specific measures/activities for improvement, and their monitoring and evaluation. Technically, the model is qualitative and rule-based, developed according to the DEX (Decision Expert) method (Bohanec, 2022). Another important part of the certificate is the assessment of the current *mobility structure of employees* and *potential* for its improvement, which is aimed at perpetual monitoring and managing of the situation. The certificate proposal also defines the certification process and means of acquiring the necessary data, which includes interviews with the organisation's management and surveys of employees' mobility behaviour.

In what follows, we first describe our approach to the development of the certificate, which included a study of the state-of-the-art on the topic and related work, and identification of possible certification criteria. This is followed by a presentation of certificate concepts, with special emphasis on the DEX model and an example of its application.

2. Methodological Approach

As the first stage of certificate development, we conducted a thorough state-of-the-art analysis (Bohanec, et al., 2022). The two main findings, which considerably shaped our further work, were:

1. We could not find any existing certificate that would fully meet the goals (section 3) we had set for ours.
2. Multi-criteria decision-modelling methods (MCDM) (Greco, et al., 2016; Kulkarni, 2022) are well established and widely used in the area of sustainable urban mobility planning (SUMP) (Garcia-Ayllon, et al., 2021).

Actually, there exist certificates that in some way address the aspects of mobility and sustainability. In Slovenia, there are three well-established certificates: Green Star[2], Cyclists-Friendly Employer Certificate[3] and Pedestrian-Friendly Organization[4]. The former addresses general aspects of green transformation and climate action, and only barely touches upon sustainable mobility. The latter two are specific and address only cycling and walking, respectively, as sustainable means of mobility. Some comparable certificates are used in Norway (Bohanec, et al, 2022), too, such as "Eco-lighthouse" and "Bicycle-Friendly Workspace". Overall, we were surprised by a relatively poor coverage of employers- and employees-related topics in the scientific literature. However, this topic was much better covered in research projects, such as CIVITAS[5], ENDURANCE[6],

[2] https://www.green-star.si/
[3] https://cfe-certification.eu
[4] https://www.sptm.si/application/files/3116/3584/8163/Izhodisca-in-kriteriji-za-pridobitev-certifikata-pesci.pdf
[5] https://civitas.eu/
[6] https://www.rupprecht-consult.eu/project/endurance

CH4LLENGE[7] and ELTIS[8], where we found a number of useful recommendations and tips for evaluating sustainable mobility of organizations and their employees. The principles advocated there have been meticulously translated into the development of the SmartMOVE certificate.

During the literature review, we systematically collected sustainability indicators and criteria that could be used – directly or adapted – for our purpose. Ultimately, we made a collection of more than 100 criteria (Bohanec, et al, 2022). Most of them address Economic, Environmental and Social aspects of SUMP. Somewhat less frequently mentioned aspects are also Technical, Security, Political, Implementation, Promotional, Institutional, Infrastructure, and Management. While this collection turned out too wide for the sole purpose of certification, it gave us a good starting point and a number of criteria to choose from. Among the reviewed studies, the most useful were those that addressed specific decision problems, for example introduction of shared transport resources in cities (Cieśla, et al., 2020), and sustainable urban mobility evaluation at specific locations or organizations (Zapolskytė, et al., 2020; Ortega, et al., 2021). The work of Awasthi, et al. (2018) stands out for a very clear structure of SUMP-assessment criteria.

Considering the data acquisition from employees and managers of an organization, we were most convinced by SUMP self-assessment questionnaires developed in the CH4LLENGE project, which consist of series of carefully designed and as-simple-as-possible yes-no questions. We chose to follow their general approach, but formulated our own set of questions/criteria that specifically address sustainable mobility of employees in organizations.

3. The SmartMOVE Certificate

3.1. Purpose

The SmartMOVE certificate is intended to raise awareness and promote the sustainable mobility of employees in organizations. It can be rewarded to any organization that:

- continuously monitors travel habits and mobility structure of its employees,
- designs and implements activities to improve sustainable mobility, and monitors and evaluates their results,
- shows a good state and/or sufficient improvement of sustainable mobility.

The certificate explicitly addresses only the mobility of *employees* and excludes other means of transportation, such as for logistics, which would require a different approach.

3.2. Requirements

The basic requirements for the certification process and corresponding criteria are:

- Minimality: The certification methodology should include as few relevant criteria as possible.
- Operability: All used criteria must be measurable and obtainable relatively easily through surveys and interviews with the organisation's representatives.
- Simplicity: The approach should be effective and simple enough for its users.

The simplicity requirement clearly distinguishes this certificate from *mobility plans*, which are commonly developed in relation with sustainable mobility (Kiba-Janiak, Witkowski, 2019; Rupprecht, et al., 2019). Although both require a fairly detailed insight into the organization's mobility structure and its relationship to sustainable mobility, the certificate is intended as a significantly simpler (and cheaper) approach. The certification process could be roughly described as a subset that corresponds to the initial part of creating mobility plans; it excludes a detailed consideration of specific activities, which are an integral part of mobility plans and require a lot of work. Having a mobility plan is not required for obtaining the certificate.

[7] http://www.sump-challenges.eu/ - Addressing the four key challenges of sustainable urban mobility planning
[8] https://eltis.org - The EU Urban Mobility Observatory

The certification process should be performed by a reputable organization with properly trained auditors. The procedure must be clear and have clear objectives, equal for all – thus the need for an explicit evaluation model. Also, the certification process must be self-sustaining: the foreseen procedures and instruments must provide all the data necessary for the certificate awarding decision.

Regardless of the final decision – whether the organization receives a certificate or not – the process is also expected to show a clear picture of the state of sustainable mobility in the organization, its strengths and weaknesses, and above all, suggest possibilities for future improvements.

3.3. Certification process

The proposed certification procedure consists of three steps:

1. Preliminary self-evaluation: Unsupervised and free of charge, performed by the candidate organizations themselves using a simple and publicly available questionnaire, consisting of ten questions. The aim is to determine whether the organization meets the essential requirements for obtaining the certificate.
2. First certification: Carried out in collaboration with the organisation and certification auditor. The aim is to assess the state of sustainable mobility in the organization. This includes two major categories: (1) general assessment from various aspects, such as organization, vision, plans, implementation and monitoring of activities, etc., and (2) travel habits, mobility structure and potential for further improvement. The category (1) is assessed by the multi-criteria model, further detailed in section 4. The category (2) is assessed through employee surveys and numeric models, which are not presented here.
3. Renewal of the certificate: Carried out after the certificate expires (provisionally each three years). The process incudes the main step, which is exactly the step 2 above, and an additional step: reviewing the changes and results of the previous period, in order to determine whether sustainable mobility in the organization improved, worsened or remained at approximately the same level. The certificate is not renewed if the status has worsened substantially.

4. Qualitative Multi-Criteria DEX Model

The central component of the SmartMOVE certification method is a qualitative multi-attribute rule-based model, developed according to the DEX method. The model defines criteria for granting the certificate; in total, there are 50 criteria (not shown here for space limitation) that address various aspects of sustainability, from criteria addressing the management of sustainable mobility in the organisation, to those addressing general activities toward improvement (e.g., education of employees) and specific measures addressing sustainable means of transportation. According to certificate goals (section 3.1), which aim to reward organizations that are aware and already take good care of sustainable mobility, we formulated eight criteria that must be necessarily fulfilled:

1. Established (planned and regularly addressed) commitments regarding sustainable mobility.
2. Perpetual monitoring of travelling habits and mobility structure of employees.
3. Having a policy, strategy or plan for incorporating the principles of sustainable mobility.
4. Assigned a person or body for the coordination of sustainable mobility activities.
5. Cooperation with research or consulting organisations regarding sustainable mobility.
6. Having recognized the potential for sustainable mobility transformation.
7. Building awareness and educating employees.
8. Having planned, ongoing or already implemented sustainability measures.

These and the remaining 42 criteria are assessed through the discussion between the organisation's representatives and the auditor. The DEX model is qualitative, thus the fulfilment of individual criteria is expressed in terms of a three-valued scale {no, partly, yes}. These assessments are guided by the *Auditor's Manual* (currently available only in Slovenian language) that consists of a questionnaire addressing all individual criteria and prescribing conditions for assigning criteria values.

Attribute	Scale
CERTIFICATE	**unacc**; acc; good; ***exc***
├**BASICS**	**unacc**; acc; good; ***exc***
├POTENTIAL FOR SUCCESS	**unacc**; acc; good; ***exc***
└**ORGANIZATION**	**unacc**; acc; good; ***exc***
├Management	**no**; partly; ***yes***
├Research and experience	no; partly; ***yes***
└Adaptation of work	no; partly; ***yes***
├**VISION AND GOALS**	**unacc**; acc; good; ***exc***
├SITUATION AND SCENARIOS	**unacc**; acc; good; ***exc***
├VISION	**unacc**; acc; good; ***exc***
└PRIORITIES AND GOALS	**unacc**; acc; good; ***exc***
├**MEASURES**	**unacc**; acc; good; ***exc***
├GENERAL MEASURES	**unacc**; acc; good; ***exc***
└**SPECIFIC MEASURES**	**unacc**; acc; good; ***exc***
├**Sustainable modes of transport**	**unacc**; acc; good; ***exc***
├Walking	no; partly; ***yes***
├Cycling	no; partly; ***yes***
└Public transportation	no; partly; ***yes***
├Motorised vehicles	no; partly; ***yes***
└Measures for customers	**unacc**; acc; good; ***exc***
└**ACTING AND MONITORING**	**unacc**; acc; good; ***exc***
├SPATIAL PLANNING	no; partly; ***yes***
├RESPONSIBILITY AND FINANCING	**no**; partly; ***yes***
└MONITORING AND EVALUATION	no; partly; ***yes***

Figure 1: Top-level structure of the certificate evaluation DEX model.

The 50 criteria are then aggregated according to the model hierarchy. The top-level structure of criteria is shown in Figure 1. The root criterion is called CERTIFICATE and represents the overall assessment, using the four-valued scale: {unacceptable, acceptable, good, excellent}. Capital letters denote criteria that correspond to particularly important aspects of sustainable mobility, which are assessed in the process:

- POTENTIAL FOR SUCCESS: Considering the organisation's management and leadership, awareness of the mobility situation, and orientation and commitment towards sustainable mobility.
- ORGANIZATION: Considering the management of sustainable mobility on the organization and collaboration with other organisations, such as research and consulting organizations and neighbouring organizations that might share the same mobility space, issues and policies.
- SITUATION AND SCENARIOS: Knowledge of traveling habits of the employees, identification of relevant stakeholders, and awareness of the mobility structure and potentials.
- VISION: The existence and level of sustainability mobility plans, long-term vision of the organization in the area of sustainable mobility.
- PRIORITIES AND GOALS: The existence and quality level of sustainable mobility priorities and goals, with particular emphasis on monitoring SMART (Specific, Measurable, Achievable, Relevant, Time-bound) targets.
- GENERAL MEASURES TO IMPROVE MOBILITY: Conducted or already implemented general measures/projects, such as education of employees, providing appropriate information (e.g., maps with mobility options and public transport timetables).
- SPECIFIC MEASURES TO IMPROVE MOBILITY: Specific measures regarding various means of sustainable transportation: walking, cycling, public transportation, and reducing the use of individual cars. For instance, cycling incorporates measures: easy access, parking lots and stands, proximity to the entrance, measures against theft, maintenance kits, bikes available at the workplace, awards for cycling to work and discounts for employees for purchasing bike equipment.

- SPATIAL PLANNING: Local arrangement of space, traffic and facilities.
- RESPONSIBILITY AND FINANCING: Action plans and ongoing activities for sustainable mobility.
- MONITORING AND EVALUATION: Perpetual monitoring and evaluation of completed and ongoing sustainable mobility projects and measures.

Regarding the value scales of criteria (Figure 1) it is worth noting that the red colour indicates undesired values that lead to rejection of the certificate. For instance, the red "no" denotes that Management is an essential criterion that has to be at least partly fulfilled. The black "no" that occurs with some other criteria tells us that they are still important, but not essential. The green colour indicates particularly advantageous values.

Table 1: Decision rules for assessing ORGANIZATION.
'>=' and '<=' mean 'better or equal' and 'worse or equal', respectively.
'*' represents any value.

	Management	Research and experience	Adaptation of work	ORGANIZATION
1	**no**	*	*	**unacc**
2	partly	no	<=partly	acc
3	partly	<=partly	no	acc
4	>=partly	no	no	acc
5	partly	*	***yes***	good
6	partly	>=partly	>=partly	good
7	partly	***yes***	*	good
8	***yes***	no	partly	good
9	***yes***	partly	no	good
10	***yes***	*	***yes***	***exc***
11	***yes***	>=partly	>=partly	***exc***
12	***yes***	***yes***	*	***exc***

The aggregation of values in the model is governed by decision rules. Table 1 shows decision rules for determining the value of ORGANIZATION with respect to three lower-level criteria: Management, Research and experience, and Adaptation of work. For all possible combinations of values of these three criteria, the corresponding value of ORGANIZATION is given in the rightmost column. It is easy to see that Management is indeed an essential criterion: whenever its value is "no", ORGANIZATION is "unacceptable", regardless of the remaining two criteria (rule 1). Other value combinations lead to other (acceptable or better) values of ORGANIZATION.

Similar decision tables are defined for all aggregate criteria in the model, i.e., those that depend on lower-level criteria. In total, there are 31 such tables. Thanks to automatic verification carried out by the DEXiWin software[9], which was used to develop the model, all decision tables are complete (they define outputs for all input combinations) and consistent (the better input value always leads to a better or the same output assessment).

Notice that DEX is a qualitative MCDM method and there are, in principle, no weights associated with criteria. The certificate result is determined by a bottom-up aggregation of 50 input questionnaire values, according to the structure of the model (Figure 1) and decision rules (example in Table 1). Decision rules were designed to ensure that the eight required criteria are considered more important than others in the sense that when they are not fulfilled, the final evaluation is "unacc" and the certificate cannot be awarded. The remaining criteria have similar impact with respect to each other, however their "importance" (in the sense of MCDM weights) varies depending on values of other criteria in the same context. Consider, for example, rule 12 in Table 1. When both Management and Research and experience are "yes", then Adaptation of work is not really important (denoted by '*') to assess the ORGANIZATION as "exc". By the same token, rule 10 declares Research and experience not important whenever both Management and Adaptation of work are evaluated as "yes".

[9] https://dex.ijs.si/dexisuite/dexiwin.html

5. An Example Application

Currently, the proposed approach is in the testing stage. So far, it has been verified on a sample of five organisations that collaborate with SmartMOVE. In the following we show an example application at Jožef Stefan Institute (JSI). JSI[10] is the largest and leading Slovenian scientific research institute, covering a broad spectrum of basic and applied research. The staff of around 1,200 specialize in physics, chemistry and biochemistry, electronics and information science, nuclear technology, energy utilization and environmental sciences. JSI has facilities in two locations. The headquarters and main facilities are located in a densely populated in the SW part of Ljubljana, and the other location is the Reactor Center Podgorica, located approximately 10 km out of the main city area. Although sustainable mobility is regarded by JSI as an increasingly important concept, it has not been addressed in a systematic and organised manner yet.

The experiment involved two JSI departments (of Knowledge Technology and Environmental Sciences), with collectively about 100 employees working at both locations. The assessments of input criteria in the DEX model were obtained in collaboration with JSI environmental experts, who are experienced in the area of sustainable mobility. Employing the DEX model yielded top-level results as shown in Figure 2.

Attribute	JSI
CERTIFICATE	**unacc**
├**BASICS**	**unacc**
├POTENTIAL FOR SUCCESS	**unacc**
└**ORGANIZATION**	good
├Management	partly
├Research and experience	partly
└Adaptation of work	***yes***
├**VISION AND GOALS**	acc
├SITUATION AND SCENARIOS	acc
├VISION	acc
└PRIORITIES AND GOALS	acc
├**MEASURES**	***exc***
├GENERAL MEASURES	good
└**SPECIFIC MEASURES**	***exc***
├**Sustainable modes of transport**	***exc***
├Walking	***yes***
├Cycling	***yes***
└Public transportation	***yes***
├Motorised vehicles	***yes***
└Measures for customers	acc
└**ACTING AND MONITORING**	acc
├SPATIAL PLANNING	no
├RESPONSIBILITY AND FINANCING	partly
└MONITORING AND EVALUATION	no

Figure 2: Assessment of the mobility situation at JSI.

Attribute	JSI
CERTIFICATE	**unacc**
├**BASICS**	**unacc**
├**POTENTIAL FOR SUCCESS**	**unacc**
├**Management**	**no**
├[1] Management commitment	**no**
└[5] Management as a role model	no
├[2] Stakeholders	no
├[3] Status and objectives	no
└[4] Recognition of opportunities	**no**

Figure 3: Assessment of the JSI POTENTIAL FOR SUCCESS. Numbers in brackets refer to individual questions.

Overall, the results indicate that JSI is currently not eligible for obtaining the SmartMOVE certificate. The main reason is the unacceptable assessment of POTENTIAL OF SUCCESS. A deeper analysis of the corresponding subtree of criteria (Figure 3) reveals that such assessment is due to the inactivity of JSI in addressing and managing sustainable mobility issues, and having not assessed the corresponding opportunities and potentials. On the other hand, the situation regarding general and specific sustainability measures is actually very good. Consequently, JSI has a very good potential for obtaining the certificate, subject to improvements that should particularly address the organizational aspects: assigning a sustainable mobility

[10] https://www.ijs.si/ijsw/V001/JSI

manager, explicitly formulating vision and goals, and, subsequently, monitoring and assessing the effects of activities. Regarding specific actions, only minor improvements of walking pathways and city bike stations might be beneficial.

6. Conclusions

We have presented an ongoing development of the SmartMOVE certificate, a mechanism for awarding and encouraging organisations for taking care of sustainable mobility of their employees. This includes a continuous monitoring of employees' travel habits and mobility structure, planning and implementing relevant activities, monitoring and evaluating their effects and impacts, possibly achieving and maintaining a good sustainable mobility standard. The main element is a qualitative multi-criteria DEX model, which was specifically addressed in this paper.

In its current form, the model consists of 50 basic (input) and 31 aggregate (result) criteria. The final assessment, which determines the eligibility of the company to receive the certificate, is located at the very top of the model (called CERTIFICATE). Important aspects of evaluation are also obtained at the first and second levels of the model and effectively explain the reasons for the final assessment. The model also facilitates experimentation and can answer the important question: what the organisation needs to change for a better evaluation the next time?

So far, the model has been tested on a sample of five organisations and the results are encouraging. The method is indeed operational and in all use cases we were able to obtain the necessary data relatively easily. This typically means conducting an online survey of (a sample) of employees and conducting two to three meetings with representatives of the organisation.

The proposed approach is not necessarily tied to the certificate, but may have a wider applicability. To the best to our knowledge, it is the most detailed assessment system focusing particularly on sustainable mobility of employees. Even if an organization does not apply for the certificate, it can very clearly recognize their positive achievements and challenges. Compared to the development of a mobility plan, the process is easier, faster and cheaper. Even though it cannot provide all the results we expect from a mobility plan (a detailed overview of the situation, a proposal for specific measures and activities, investment planning), it is nevertheless useful as an initial step.

In the future, we will continue verifying the approach and improving it along the way. However, the main future concern is to establish the certificate as an approved and highly respected means for rewarding organisations that contribute to sustainable mobility. This requires much more than a good assessment approach, particularly a wide public recognition and governmental support.

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Human-Centric Decision and Negotiation Support for Societal Transitions

Generative Adversarial Networks for Virtual Fluorescent Staining

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Abstract

Fluorescent staining plays a crucial role in clinical pathology and life-science research for visualizing tissue and cellular structures. However, traditional staining methods are invasive, hindered by cost, time, and environmental impact. Deep learning has emerged as a transformative approach to address these challenges by computationally generating virtually stained images from label-free samples. We introduce a Wasserstein Generative Adversarial Network (WGAN) for three-dimensional fluorescent staining, leveraging multi-channel data to exploit the positive and negative colocalization information of cellular structures. The proposed model surpasses conventional U-Net architectures, producing sharper and more realistic images. Additionally, we designed a classification perceptual metric to evaluate the realisticness of the generated images that better correlates with expert evaluation.

Keywords: virtual staining; GAN; label-free; cellular structures; perceptual metric

1. Introduction

Histological and cytological staining is a key method of examining tissue and subcellular structures in clinical pathology and life-science research. This technique involves the use of chromatic dyes or fluorescent labels to visualize tissue and cellular structures, facilitating their microscopic assessment.

Traditional chemical staining is expensive, time-consuming, difficult to use on in vitro cultures, and allows only a limited number of structures to be stained and observed on the same specimen due to the limited spectrum of stains available and their spectral overlap. Moreover, the toxic chemical compounds used generate significant amounts of waste and can alter the analyzed section, preventing additional staining and further analysis.

Deep learning techniques have opened up new possibilities for staining methods, generating virtually stained images from label-free images. This breakthrough offers fast and cost-effective alternatives for visualizing tissue and cellular structures. It has the potential to make tissue and cellular examination more accessible, particularly in resource-limited settings, and to make it possible to perform in vivo imaging.

For this image-to-image translation task, the model is trained to predict the target cellular structures, represented by the fluorescent channels of the target images, starting from label-free (e.g., transmitted-light) images of the sample. Models used for this task are usually based on a U-Net architecture, either trained to minimize a pixel-wise loss function that measures the dissimilarity between the prediction and the target or used as the generator in a conditional generative adversarial network (cGAN).

In this work, we present a novel Wasserstein GAN with Gradient Penalty (WGAN-GP) (Arjovsky, Chintala, and Bottou 2017; Gulrajani et al. 2017) model that can take full advantage of three-dimensional and multi-channel information of our data.

This technology assists decision-makers with enhanced tools for analysis and diagnosis. Its fast and cost-effective nature makes tissue and cellular examination more accessible, empowering decision-makers in areas with limited resources to perform necessary analyses and make critical decisions regarding patient care and research direction.

The potential for in vivo imaging opens up new possibilities for decision-making in real-time clinical settings. By enabling non-invasive visualization of tissue and cellular structures within living organisms, this technology supports rapid decision-making regarding diagnoses, treatment plans, and interventions.

The use of three-dimensional and multi-channel information in the model enhances the depth and accuracy of the generated images. This comprehensive representation of cellular structures has the potential to provide decision-makers with a more complete understanding of tissue morphology and pathology. Traditional staining often limits the number of structures visualized due to the spectral overlap of dyes. Virtual staining, with its potential for more complex image analysis, could allow researchers to examine a wider range of cellular features simultaneously. This can provide a more comprehensive picture of the tissue, leading to more informed decisions about treatment options or disease progression.

Overall, the integration of deep learning techniques for image-to-image translation in histological and cytological staining significantly advances decision-making capabilities in clinical pathology and life science research by improving visualization, accessibility, and accuracy of cellular analysis.

2. Background and related works

The term “virtual staining” is broadly used to refer to methods that digitally emulate stains using trained deep neural networks, including label-free staining, in-silico labeling, and stain-to-stain transformations. This task consists of digitally replicating cellular structures as they would be seen if labeled with specific fluorescent tags.

Deep learning enabled incredible possibilities for virtual staining, that were explored in the past years (Bai et al. 2023). In 2018, Christiansen et al. proposed the first work utilizing a deep learning approach to in-silico labeling, developing a single model that simultaneously predicts eight different fluorescent channels. In their work, the 3D information is only used to improve the accuracy of the model when predicting the fluorescence channels corresponding to the central slice of the z-stack (Christiansen et al. 2018). In the same year, Ounkomol et al., investigated a model for fluorescent label prediction that takes as input three-dimensional transmitted-light (TL) live cell images, establishing that 3D patterns are valuable for predicting subcellular organization. Their model uses a U-Net (Ronneberger, Fischer, and Brox, 2015) architecture trained to minimize the mean squared error (MSE) between generated and ground truth fluorescent channels. Their model does not perform simultaneous prediction of multiple fluorescent channels. Instead, they train a different model for each structure. In 2019, Rivenson et al. published the first GAN architecture for virtual staining. In their model, the discriminator is not conditioned on the source unstained auto-fluorescence image, so it only penalizes fake-looking images, but not images that look realistic while not being realistic fluorescent labeling of the source unstained image (Rivenson et al. 2019). Isola et al. found that for image-to-image transformation tasks, adding the source image to the input of the discriminator usually produces better results (Isola et al. 2018). In 2022, Cross-Zamirski et al. proposed a Wasserstein GAN with Gradient Penalty (WGAN-GP) model for the prediction of five two-dimensional fluorescent channels. This architecture improves the training stability of GANs and has been shown to optimize many image similarity metrics between generated images and targets better than U-Nets (Cross-Zamirski et al. 2022).

2.1 Our contributions

The work presented here tries to combine all the insights and promising features of these previous works. Our model takes as input 3D images and outputs 3D images like Ounkomol et al. (2018). To take advantage of the correlation and additional information present in the other channels, our model is trained

to predict multiple fluorescent channels simultaneously. Each sample in our training data, as in the dataset of Christiansen et al. (2018), only has three fluorescent labels. Therefore, to train the model, we apply the same idea of a masked loss used in their work. To deal with coherence and lack of finer details, we use a conditional GAN approach. In particular, we used a WGAN-GP model, like Cross-Zamirski et al. (2022), that was found to perform very well thanks to its stability in training. Moreover, the model designed here has the only requirement for the input images to have at least 8 pixels on one of the axes and deals with the three dimensions in the same way. Thanks to this feature, our model is almost completely agnostic to the size of the input images, removing the need to stitch together predicted patches from multiple steps of inference.

To the best of our knowledge, this is the first work to develop a single GAN model that simultaneously predicts different fluorescent channels, exploits the three-dimensional information present in the data, generates 3D images for each fluorescent channel, and eliminates the need to stitch together predicted patches from multiple inference steps.

3. Dataset and data preprocessing

The dataset we used is the hiPSC Single-Cell Image Dataset from the Allen Institute for Cell Science (Viana et al. 2023). The dataset comprises images of live cells from 25 isogenic human induced pluripotent stem cell (hiPSC) lines from the Allen Cell Collection. Cells were imaged live and in 3D, as a z-stack of two-dimensional images, at high resolution (120x/1.25 NA), generating 18186 fields of view (FOVs) in four acquisition channels, representing the FOV-specific protein, the cell membrane, the DNA, and the transmitted-light channel.

Portions of each FOV suffer from defocus aberration and noise. This is especially relevant for the intended target channels and thus the training of our model. The dataset was therefore processed to mitigate these problems.

3.1. Selection of in-focus slices

In order to automatically select the in-focus z-planes in the z-stack, we compute the power spectrum log-log slope (PLLS) (Bray et al. 2012). This measure evaluates the slope of the power spectral density of the pixel intensities on a log-log scale. The power spectrum shows the strength of the spatial frequency variations as a function of frequency. It is always negative and usually decreases in value as blur increases and high-frequency image components are lost (more negative values indicate a steeper slope, which means that the image is composed mostly of low spatial frequencies).

In our case, PLLS works well to spot the on-focus region, but behaves the opposite as expected regarding its values: PLLS is consistently more negative for on-focus images. We believe this behavior to be due to the presence of noise. Experiments with denoising suggested that in our images the high-frequencies don't represent structure but rather noise, which is equally present in on-focus and out-of-focus images. The difference resides in medium frequencies, that in our images encode the structure we want to visualize. The higher power of medium frequencies in on-focus images makes the power spectrum slope steeper, and hence more negative (see Figure 1).

3.2. Denoising

When we train a model with the generative adversarial framework, the noise in the ground truth images becomes a problem because it gives the discriminator an easy way to distinguish between real and generated images, making the job of the discriminator even easier than it already is, with bad consequences for training stability.

To denoise our target images we used Noise2Void (Krull, Buchholz, and Jug 2019), a deep learning based technique that exploits the assumption that signal has a predictable structure, while noise doesn't. This allows to train the denoising model directly on the body of data to be denoised, so there is no need for clean targets.

Noise2Void made it possible to denoise our dataset with results comparable to classical methods like block-matching and 3D filtering (BM3D) in a fraction of the time and without the need to estimate the amount of noise beforehand.

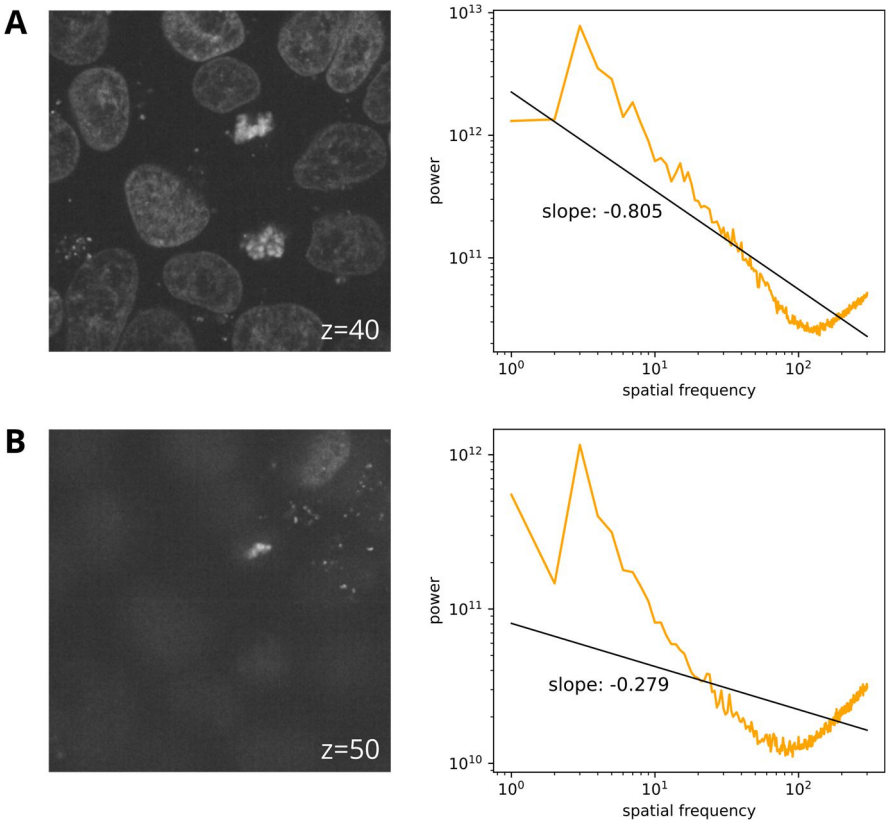

Figure 1: Power spectrum plots for an in-focus slice (**A**) and a defocused slice (**B**) of the same sample (DNA channel).

4. Architecture and training setup

Our model is a WGAN-GP (Arjovsky, Chintala, and Bottou 2017; Gulrajani et al. 2017), where the generator is a U-Net (Ronneberger, Fischer, and Brox 2015) and the critic follows the design of a PatchGAN discriminator (Isola et al. 2018).

Our generator is a U-Net of depth 3. The downsampling path is composed of convolutional blocks with 64, 128, and 256 filters respectively. Each block is composed by two identical sub-blocks made of a 3D convolution with a kernel size of 3, stride 1, and padding 1, followed by instance normalization and Leaky ReLU activations. Between blocks, a 3D convolution with kernel size 2 and stride 2 performs the downsampling halving the spatial dimensions.

The upsampling path is symmetric to the downsampling, with transposed convolutions. The skip connections from the downsampling path are concatenated with the corresponding feature maps during the upsampling path to facilitate information flow across different scales. The final layer employs a 3D convolution with kernel size 3 and padding 1 to generate the 6 fluorescent channels as the output. In total, our generator has 23.1 M trainable parameters. (Figure 2)

The critic is composed of five convolutional blocks. The first one is followed just by a Leaky ReLu activation, while the others perform instance normalization before. The first three blocks perform convolutions with a kernel size of 4, stride of 2, and padding of 1, while the last two preserve the spatial

dimensions using a kernel size of 3, stride of 1, and padding of 1. The final layer has a receptive field of size 54, so the critic model can only penalize unrealistic structure at this scale. (Figure 3)

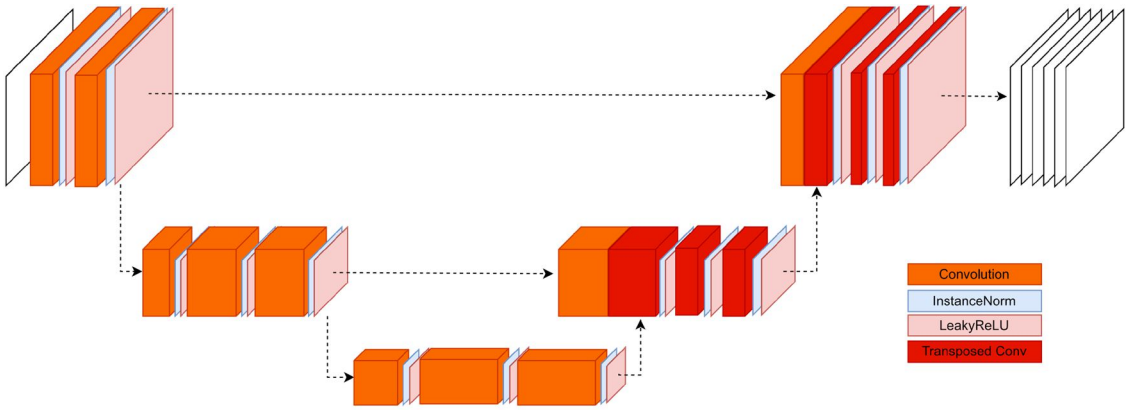

Figure 2: **Generator architecture diagram**

Downsampling path composed of convolutional blocks with 64, 128, and 256 filters respectively. Each block is made of two identical sub-blocks (3D convolution with a kernel size of 3, stride 1, and padding 1, followed by instance normalization and Leaky ReLU activations). Between blocks, a 3D convolution with kernel size 2 and stride 2 performs the downsampling halving the spatial dimensions. The upsampling path is symmetric to the downsampling, with transposed convolutions. The skip connections from the downsampling path are concatenated with the corresponding feature maps during the upsampling path. The final layer employs a 3D convolution with kernel size 3 and padding 1 to generate the 6 fluorescent channels as the output.

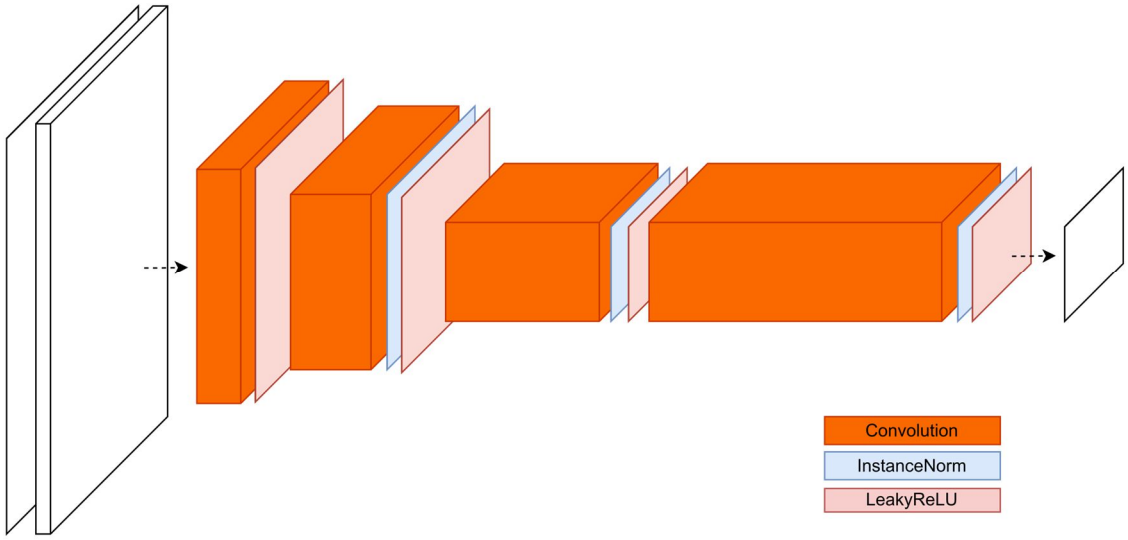

Figure 3: **Discriminator architecture diagram**

Five convolutional blocks in succession: the first one is followed just by a Leaky ReLu activation, while the others perform instance normalization before. The first three blocks perform convolutions with a kernel size of 4, stride of 2, and padding of 1, while the last two preserve the spatial dimensions using a kernel size of 3, stride of 1, and padding of 1.

4.1. Loss function

The loss function of our generator model is a weighted sum between the L1 distance and the adversarial loss calculated by the PatchGAN discriminator, which encourages local realism. Each ground truth sample presents just three populated channels (DNA, cell membrane, and a sample-specific structure) while the others are just void. To deal with this, we follow a similar procedure as in

(Christiansen et al. 2018): the image produced by the generator is masked and the pixel-wise component of our loss is computed only between the corresponding populated channels.

Regarding the adversarial component of the loss, we feed the critic model with the masked generated image, so that it has the same amount of void channels as a real sample, and the critic can't use the number of non-zero channels as additional info to distinguish between fake and real samples.

5. Evaluation

Evaluating the quality of synthesized images is an open and difficult problem (Theis, Oord, and Bethge 2016). Using pixel-wise metrics for evaluation presents the same issues as using them as losses for training (e.g. rewarding blurry results). Moreover, the absolute value of image metrics is greatly influenced by the characteristics of the data, so these metrics can be appropriately used only for the purpose of comparing models on the same data. When dealing with cellular data, a significant drawback is that they treat every pixel in the image equally, even though pixels representing cellular structures are undoubtedly more critical than background (empty) pixels. Additionally, some image channels, like the nucleoli channel, exhibit sparser content compared to other channels, resulting in a difference in the number of pixels that matter versus background pixels.

Classical evaluation frameworks for GANs make use of inception score (IS) or Fréchet inception distance (FID), but the fact that these methods don't use a specialized encoder trained on our dataset makes them unreliable for the evaluation of our model because the pre-trained models learned features are ineffective on specific domains that are far from the ImageNet dataset (Liu et al. 2018). To better evaluate our model we designed a perceptual classification metric following the intuition that if the generated images are realistic, a classifier trained on real images will have good accuracy when classifying the synthesized images.

We trained a ResNet classifier to recognize which structure it is looking at: given a 3D patch of one of the channels of a ground truth image, the model outputs to which channel it belongs. When we compare the performance of this classifier on the images generated by different models, we have a measure of how much the structure present in the output images is realistic and preserves the features that make it distinguishable from other cellular structures.

6. Results

The U-Net trained with L1 loss optimizes image metrics like structural similarity index measure (SSIM), mean squared error (MSE), mean absolute error (MAE), and Pearson correlation coefficient (PCC) better than the WGAN model (Table 1), but this does not correspond to better and more realistic output images. This is in contrast to what was found in (Cross-Zamirski et al. 2022), where the WGAN model also showed better performance for image metrics. Their WGAN model was not trained from scratch but starting from a U-Net generator pretrained to minimize L1 loss. We also experimented with this training setup, finding intermediate results between the U-Net and our WGAN, as expected, both for image metrics and for visual human expert analysis.

The perceptual classification metric we designed is in better accordance with the human eye evaluation of the produced images, giving us a better proxy for what we want to evaluate than classical metrics. In fact, our WGAN model, that produces more realistic images, with sharper edges and finer details, produces images that are recognized better by the classifier (Figure 4).

Table 1: Image metrics for each channel for the two models. The values corresponding to the best-performing model for each channel metric are highlighted in bold.

Channel	Model	SSIM	MSE	MAE	PCC	F_1 Classifier
DNA	U-Net	**0.75 ± 0.08**	**0.4 ± 0.1**	0.42 ± 0.06	**0.79 ± 0.07**	0.9750
	WGAN	0.73 ± 0.09	0.43 ± 0.14	**0.39 ± 0.07**	0.76 ± 0.08	**0.9796**
Cell membrane	U-Net	**0.69 ± 0.09**	0.6 ± 0.1	**0.43 ± 0.06**	**0.65 ± 0.08**	0.8908
	WGAN	0.64 ± 0.09	0.6 ± 0.1	0.46 ± 0.06	0.61 ± 0.08	**0.9889**
Mitochondria	U-Net	**0.79 ± 0.05**	**0.35 ± 0.06**	**0.29 ± 0.03**	**0.81 ± 0.04**	0.9086
	WGAN	0.77 ± 0.05	0.39 ± 0.08	0.31 ± 0.04	0.79 ± 0.05	**0.9528**
Nuclear envelope	U-Net	**0.85 ± 0.05**	**0.19 ± 0.04**	**0.24 ± 0.02**	**0.89 ± 0.02**	0.7707
	WGAN	0.82 ± 0.06	0.25 ± 0.05	0.27 ± 0.03	0.86 ± 0.03	**0.9410**
Myofibrils	U-Net	**0.72 ± 0.09**	0.5 ± 0.2	**0.43 ± 0.07**	0.7 ± 0.1	0.9855
	WGAN	0.7 ± 0.1	0.5 ± 0.2	0.47 ± 0.09	0.7 ± 0.1	**0.9919**
Nucleoli	U-Net	**0.93 ± 0.03**	**0.14 ± 0.05**	**0.15 ± 0.02**	**0.92 ± 0.03**	0.9500
	WGAN	0.91 ± 0.04	0.19 ± 0.06	0.17 ± 0.03	0.90 ± 0.04	**0.9789**

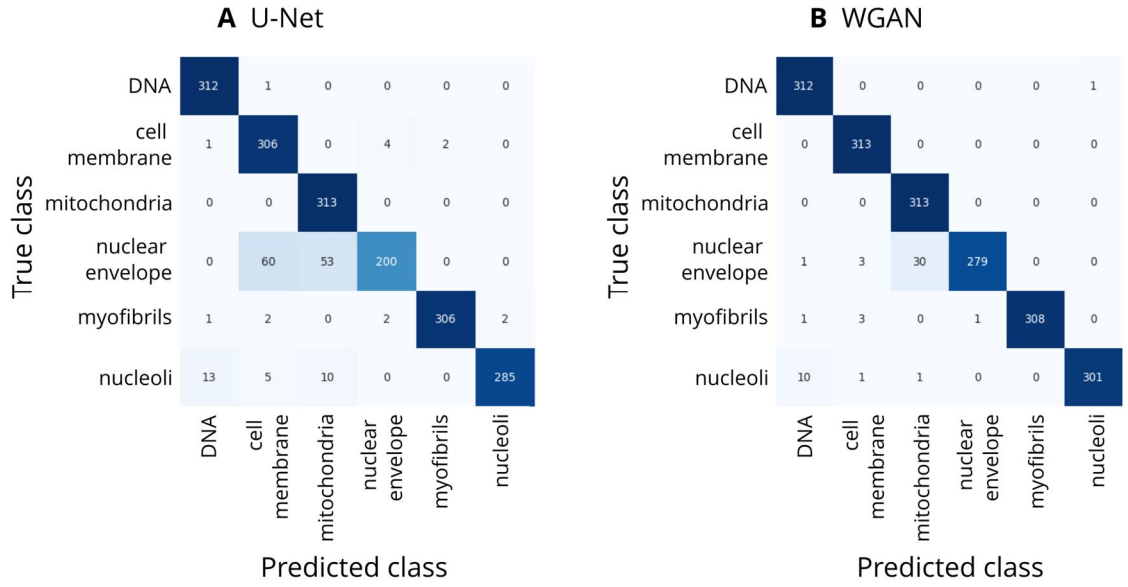

Figure 4: Confusion matrices of the classifier on images generated by (**A**) the U-Net trained with fixed L^1 loss and by (**B**) the WGAN-GP. The outputs produced by the WGAN are recognized much better by the classifier.

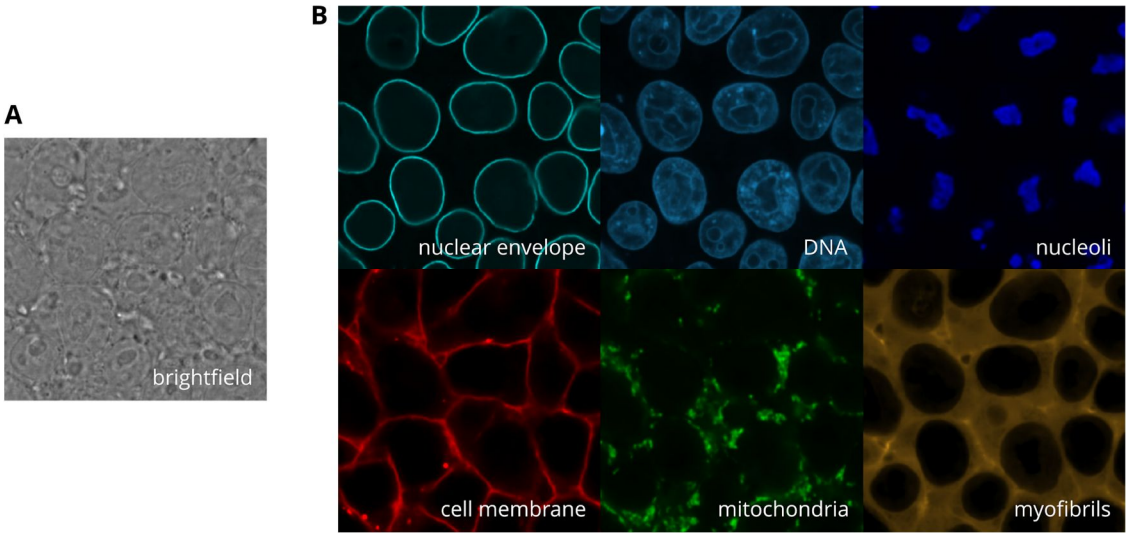

Figure 5: Input image (**A**) and model prediction (**B**) from a sample not seen in training. Each structure is shown through the central z-plane (512 x 512 pixels) taken from the 3D cube (32 x 512 x 512 pixels).

7. Conclusions and future work

Our study introduces a Wasserstein GAN model for three-dimensional virtual fluorescent staining. The model, inspired by prior works, enhances its predictive capabilities by training on 3D images and adopting a masked loss strategy for handling multiple fluorescent labels simultaneously. The use of a conditional WGAN-GP model ensures stability in training and addresses coherence and finer details, while the model's architecture allows it to be agnostic to the size of input images, eliminating the need for patch stitching.

Despite the promising contributions of our study, we should acknowledge some limitations:

- **Training data constraints:** Cytological characteristics can vary significantly among cell types, introducing challenges in capturing the diverse structures and textures. Moreover, variations in illumination, staining protocols, imaging equipment, scale, and techniques must be considered. The model may struggle to generalize well to conditions not represented in the training data, potentially leading to unreliable predictions.
- **Masked loss strategy sensitivity to sparsity:** The effectiveness of the masked loss strategy is influenced by the distribution of fluorescent labels in the training dataset. If certain labels are sparse or imbalanced, the model may prioritize more prevalent labels during training, potentially leading to suboptimal performance for rare or less frequent structures.
- **Clinical validation:** Although our model demonstrates promising results in generating 3D images of fluorescent channels, its clinical applicability and accuracy in real-world scenarios need further validation through rigorous testing on diverse clinical datasets.

To address the limitations regarding the training data, future work should be aimed at the creation of more diverse and comprehensive datasets. This includes incorporating a broader range of tissue types and imaging conditions. Diversifying the training data will enhance the model's generalizability to a wider array of tissues and clinical scenarios.

Our evaluation method could be improved by pairing our classification perceptual metric with a deep perceptual metric that compares the deep activation of the classifier when looking at real or generated fluorescence channels (Zhang et al. 2018). It would be interesting to experiment adding a term in the loss function during training representing this deep perceptual loss, like in (Dosovitskiy and Brox 2016).

The potential impact of this work extends to making subcellular and tissue examination more accessible and facilitating in vivo imaging, empowering decision-making in pathology and research, and marking a significant contribution to the field of deep learning-based staining methods.

Acknowledgments

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Human-Centric Decision and Negotiation Support for Societal Transitions

Decision support system for maturity assessment in asset management

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Abstract

Asset management (AM) is a holistic approach to managing assets to improve the delivery value of assets, which has affected the organizational results. In this context, assessing the delivery value of AM practices is essential, and maturity models (MMs) can assess this delivery. In the AM field, academics and practitioners have developed AM maturity models (AMMMs) that measure the maturity level of AM practices, using some resources as tools based on Excel or textual guidance. Analyzing available AMMMs in literature and enterprise reports, a few AMMMs are concerned about developing a decision support system (DSS) to assist AMMM applications. Considering the benefits of a decision support system for the decision-making process and the relevance of AM, this paper introduces the AMAP, a novel web DSS to support AMMM application, which has been applied in thirteen Brazilian enterprises. The aim of developing it is to improve the assessment maturity process and reduce the difficulty of the AMMM application.

Keywords: Asset management; decision support system; maturity assessment; maturity model; AMAP

1. Introduction

The interest in managing physical assets efficiently has increased in academic and business contexts (Sandu et al., 2023; Silva & Martha de Souza, 2021, Figure 1) due its relevance in contributing to organizational performance (Maletič et al., 2020; Han et al., 2021). In this scenario, asset management (AM) emerges as an interdisciplinary approach in asset-intensive enterprises that manage the assets during their life cycle (El-Akruti et al., 2013 IAM, 2008). As a result, when organizations apply AM practices, many benefits are expected, among them highlighting the value creation (ISO, 2014), that is, the AM supports the value delivery of assets. So, an aspect relevant to analyses is how the AM practices deliver value for the organization.

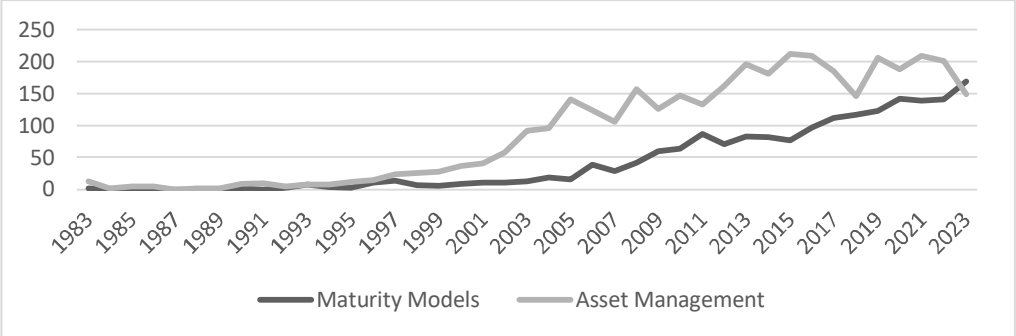


Figure 1. Annual number of articles published related to asset management and maturity model in Scopus.

Maturity models (MMs) are reference frameworks that propose a sequential maturity level that describes current practices of any process intending to guide an improvement path (Tarhan et al., 2016). MMs have been used in many management fields (Lee et al., 2019), increasing the publishing of papers relying on MM themes (Figure 1). Bititci et al. (2015) identify that MMs may improve the learning process and continuous improvement, whereas Wendler (2012) adds that MMs enhance the awareness of the analyzed aspects in

assessment and provide a systematic approach for improvement. Given the usefulness of MMs, asset management maturity models (AMMMs) have emerged to assess AM practices and programs. Investigating 18 AMMMs found in literature and enterprise reports, the following characteristics stand out:

- 78% present a self-assessment approach. In this approach, the organization can carry out the assessment itself.
- 83% do not develop assessment procedures. Most AMMMs offer few coherent prescriptions on how to apply and manage them. The assessment procedures demand a reference model of maturity to assess against current status (Tarhan et al., 2016). The absence of an assessment procedure may hinder the MM application and replicability (Lacerda & von Wangenheim, 2018).
- 16% provide a decision support system (DSS) to support the assessment maturity. Most of them make available only a data collection instrument based on Excel tools. Considering these DSSs, two was developed by entities of government (PAMCAM and Asset Management Framework) while one was developed by Institute of asset management (SAM+). These DSSs have restricted access to members of agencies, which complicates the analysis. So, it is relevant to advance in the development of DSSs to assist AMMM application.

Lima & Costa (2023) present a novel reference model developed using the design science research approaches. This AMMM is formed by ten core dimensions in AM (Table 1) that have demonstrated to be essential for AM practices, which affect business performance; a vector of weight that demonstrates the relative importance of dimension in literature; a questionnaire; and the maturity classes that describe a maturity profile of the asset-intensive enterprise.

Table 1. Dimensions of AMMM and effects on business performance

Dimension	**Benefits** (Lima et al., 2021)
AM Policy	Quality of products and services, Compliance, Learning
AM Strategy and Objectives	Compliance, efficiency, learning, competitiveness
AM Planning	Compliance, Learning, Social responsibility
Data and Information Management	Financial/profitability, Effectiveness Efficiency
Asset Information Systems	Quality of products and services, Effectiveness
AM Leadership	Flexibility
Competence Management	Flexibility Efficiency, Social responsibility, Employee performance (factors)
Risk Assessment e Management	Environmental responsibility/safety, Effectiveness, Efficiency
Asset Performance and Health monitoring	Costumers'/business partners' satisfaction, Quality of products and services, Environmental responsibility/safety, Effectiveness, Efficiency
Asset Costing and Valuation	Financial/profitability

Based on the challenges of the assessment procedure and the benefits of applying self-assessment, Lima & Costa (2023) also developed a procedure to support the application of AMMM (Figure 2) because applying self-assessment demands a structured process that provides information, steps, and techniques to complete the assessment effectively.

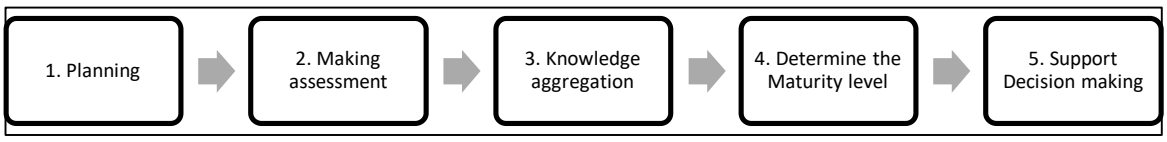


Figure 2. Assessment procedure

DSS assists decision-makers in the decision-making process by gathering and storing data to provide information for decisions that deal with uncertain and complex decision contexts (Hartono et al., 2007; Zack, 2007). It stands out that the DSS, together with a decision-maker guide for an excellent decision-making process, brings benefits for achieving better decisions (Pick, 2008). In view of these advantages, as presented in Eom & Kim (2006), DSS has been used in different fields, including the MMs area, for example, Xu et al., 2006) present a DSS to assess the innovation capability while Warnecke et al. (2019) provide a web tool to evaluate the smart city maturity with a benchmarking purpose, demonstrating the potential contribution to the AM context. Therefore, this paper presents the asset management assessment maturity procedure (AMAP), a web DSS for assessment maturity that incorporates the reference model and assessment procedure. In contrast with other DSSs, AMAP allows any asset-intensive enterprise to use it, making possible to assign the maturity class with a structured procedure free.

2. DSS for AMMM application

The AMAP was developed in Delphi language in the 2010 intraweb version and implemented on a web server, freely available at http://18.225.72.156/AMAP, which was used for thirteen asset-intensive Brazilian enterprises. The assessment data is stored in MySQL, a database management system. As mentioned, AMAP follows the AMMM and assessment procedure developed by Lima & Costa (2023), consequently, the main features of DSS are related to them. That is, the requirements for AMAP and its interface was designed to reflect the assessment procedure, so its development was not user-centered that would demand iteration with users. Moreover, it was made test with users, which have knowledge in AM and maturity models, to supply insights and points for improvements in AMAP. The AMAP features and its application are described as follows.

2.1. Assessment procedure

This section describes the steps of assessment procedure (Figure 2) in AMAP, demonstrating the mean features to performance a structure self-assessment by DSS.

Planning step

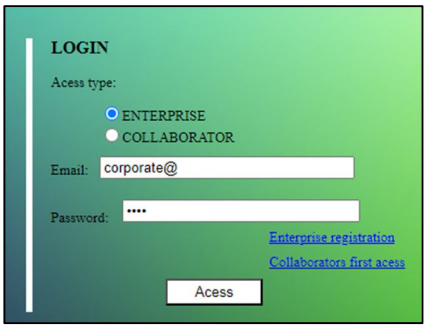


Figure 3. Window for login

The system provides individual access for the organization and its collaborators (Figure 3), with the user accessing their respective types of access that are created in the first step: planning. In this stage, the organization must follow some instructions about the allocation of resources, definition of purpose with the AM assessment, selection of collaborators that will be part of the assessment team, definition of business context, and other factors for assessment (Figure 4a), which may guarantee assessment effectiveness. Another relevant instruction is how to select collaborators to compose the assessment team. Then, based on ISO (2016), the DSS consolidates critical factors that must be considered in this selection process (Figure 4b).

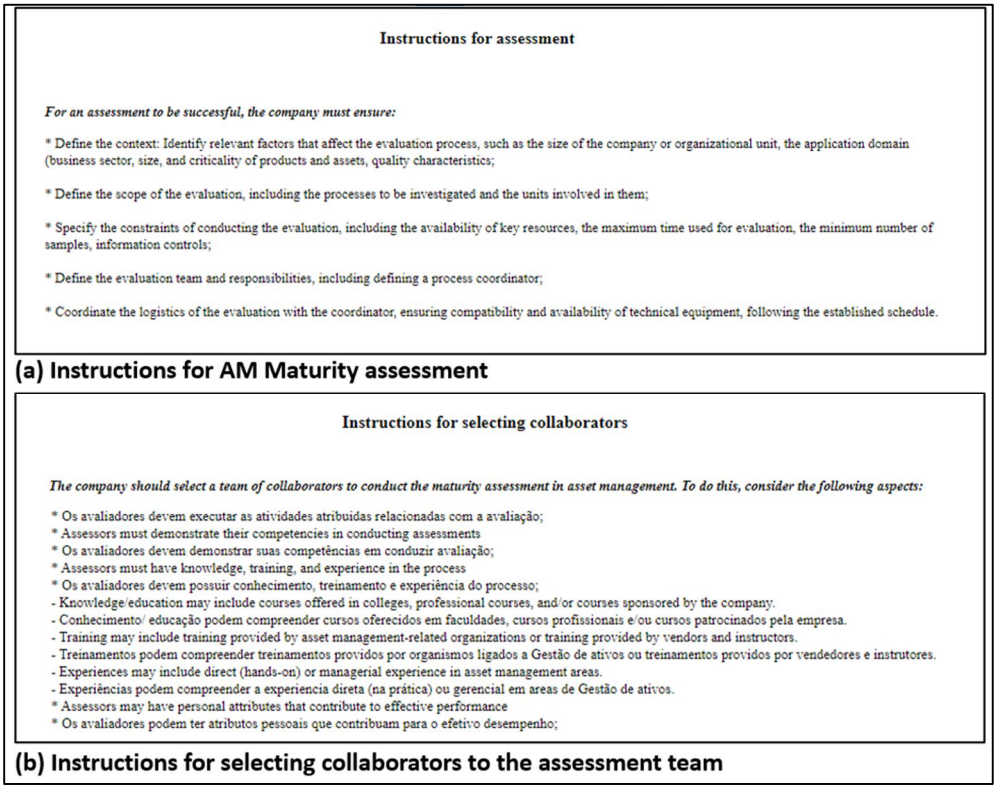


Figure 4. Windows with several instructions to improve the result of the assessment

With this relevant information and the interesting in using this system, the enterprise must register its corporate user and generate individual tokens (Figure 5a) for the member of the assessment team, these tokens are single access keys of collaborators that will assess the AM maturity. With these created tokens, the enterprise must share with the collaborators to create an individual login in the AMAP (Figure 5b).

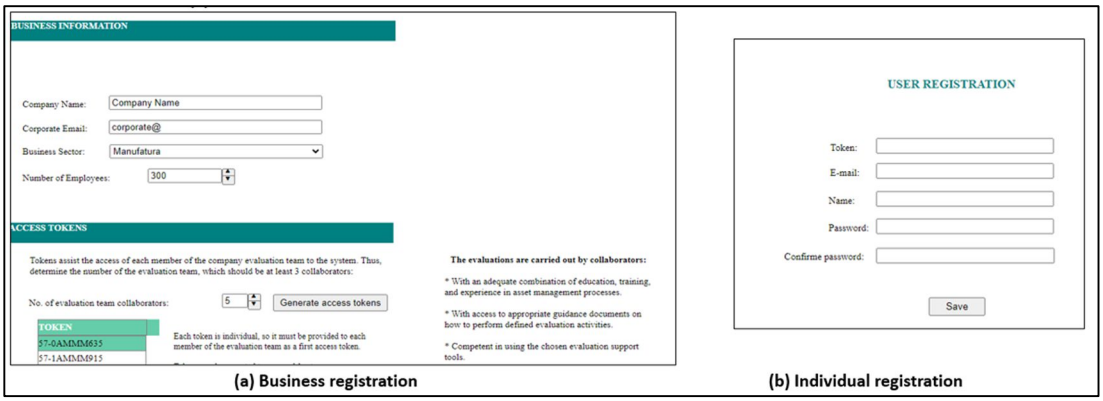


Figure 5. Business and user registration

Making assessment step

As the DSS follows a specific AMMM, the organization does not need to enter the characteristics of the reference model, such as a questionnaire. Accordingly, the organization can initiate the assessment phase. Each assessment team member receives a token and afterward creates an individual login to access the assessment window (Figure 6). The individual assessment feature allows the user to assess 30 questions that measure the capabilities of the ten AM core dimensions (Table 1). It is worth noting that each question is assessed at five

levels, representing the ability of the AM process to contribute to achieving a required AM goal, that is, the level comprises elements that demonstrate the degree of achievement of the process goal. Furthermore, as the maturity assessment is not based on opinion but on evidence, the collaborators are motivated to provide evidence for their answers.

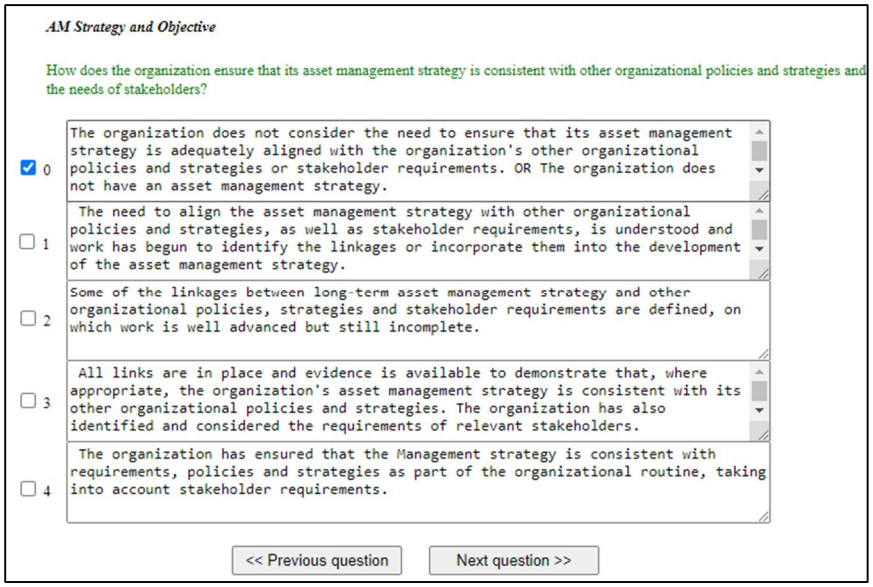


Figure 6. Window for individual assessment

Knowledge aggregation and determinate the maturity classes steps

With the answers collected, the organization should aggregate them to generate information about maturity. The knowledge aggregation and determination of maturity class steps are done totally automatically by DSS. Considering the levels given by collaborators in the question, a method based on fuzzy theory aggregates the answers to identify the capability of AM dimensions (Lima & Costa, 2023). So, the maturity level aggregates each dimension to obtain the maturity level that represents the following classes:

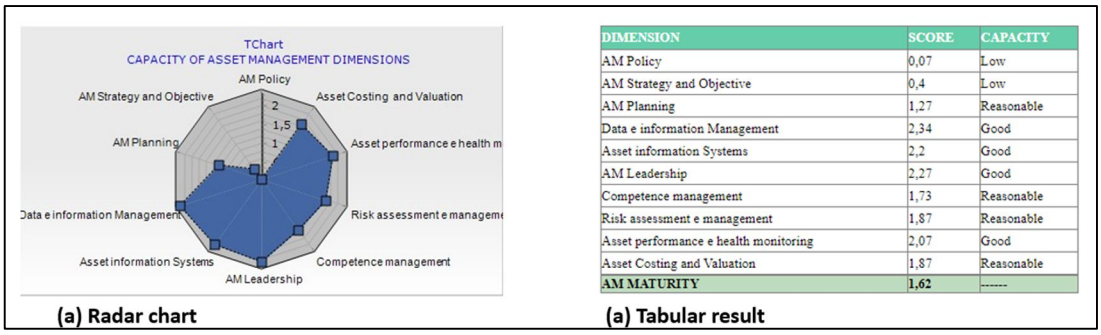
$$Class: \begin{cases} No\ applied, iff\ Ml = 0; \\ Aware, iff\ 0 < Ml < 1; \\ Developing, iff\ 1 \leq Ml < 2; \\ Competent, iff\ 2 \leq Ml < 3; \\ Optimising, \quad iff\ 3 \leq Ml < 4; \\ Excellent, iff\ Ml = 4. \end{cases}$$

The aggregation phase requires at least three complete assessments, so the organization must motivate all assessment team members to complete the evaluation. Intending to facilitate this requirement, the DSS has a monitoring window, allowing the identification of each collaborator's assessment status. Stand out that corporate users do not access the individual assessment, only the assessment status of the team, to maintain anonymity. With this requirement satisfied, the assessment procedure comes to the last step: support the decision-making.

Support decision making step

The proposed DSS gives the organization a description of AM maturity that demonstrates the degree to which AM practices deliver value based on the AM core process. The system provides different types of demonstration of results: maturity level, maturity class, graphic radar, and tabular result, which give

information for decision makers to identify the current status of AM maturity of its AM practices. AMAP has a descriptive focus, which gives information to support the decision-making process. Figure 7a illustrates the radar graph, in which the organization has a view of the performance of AM dimensions, seeing clearly the strongest and weakest dimensions. In contrast, Figure 7b presents the dimensions and maturity level results in a table. With the radar chart, the table, and the description of maturity class, the organization can check the current AM practices, and thus design the roadmap for improvement.



DIMENSION	SCORE	CAPACITY
AM Policy	0,07	Low
AM Strategy and Objective	0,4	Low
AM Planning	1,27	Reasonable
Data e information Management	2,34	Good
Asset information Systems	2,2	Good
AM Leadership	2,27	Good
Competence management	1,73	Reasonable
Risk assessment e management	1,87	Reasonable
Asset performance e health monitoring	2,07	Good
Asset Costing and Valuation	1,87	Reasonable
AM MATURITY	**1,62**	------

(a) Tabular result

Figure 7. Window for assessment result

Application and discussion

AMAP was applied in thirteen Brazilian asset-intensive enterprises of the automobile, manufacturing, electrical power transmission, cargo storage and transportation, and telecommunication sectors, in which three achieved the competent class, three in the aware class, and seven in the developing class. The DSS stores and automatically makes the calculus that assists in the decision-making process. It stands out that all managers declare that the classes assigned to the companies represents the maturity stage in asset management, therefore AMAP is capable to support the assignment of maturity class in AM. An interesting comment from users is that the model brought greater knowledge and understanding about AM, therefore it may infer that using AMAP fosters knowledges about AM practices.

Before the application guidance for the leader of the assessment team was provided with instruction for application. During the self-assessment application, the users did not report difficulties, problems, or challenges in the application, except two enterprises that had problems with firewalls of the company computers did not allow the access of website, but these issues were solved. Accordingly, it can figure out that AMAP is easy and useful to use, which has demonstrated able to support maturity self-assessment in asset-intensive enterprises.

Albeit AMAP design was not user-centered, the users provide some feedback that are useful for next improvements. Some users highlight that the layout of AMAP needs to be improved, e.g., a more interactive displays, and a more attractive and functional layout, although the current layout have not affected the usability of system. Another aspect related by users is that AMAP does not inform them that assessment finished, e.g., does not show the individual assessment or the enterprise results, so it is recommended that AMAP either providing a notification that completed the assessment or showing individual results. On the other hand, some enterprises would like to reapply the model, however AMAP stores only one assessment, demanding to enable multiples assessments.

3. Conclusions

Asset management is an exciting field for academic investigation, which has demanded studies to analyze gaps in knowledge, theories, and tools. Motivated to expand the measurement of the delivery value of AM practices, this paper presents a novel DSS to assist AMMM application.

Theoretically, this paper advances in AMMM to make available a DSS that supports maturity assessment application. In addition, it also contributes to the MM area to incorporate a self-assessment procedure in a DSS

to assist the AMMM application, which can serve as a basis for developing DSS for other contexts. Considering the ease of manipulating data through DSS, it would be interesting to progress towards a prescriptive model and new features.

From the practice perspective, the DSS may reduce the difficulties in AMMM application by enabling a structured maturity assessment, automatizing the calculus and rules steps, and centrally storing data. Through this, the organization can quickly identify the delivery value of AM practice. In the face of this, it is expected to increase the use of AMMM by asset-intensive enterprises. In addition, deeper studies with users to investigate the performance of AMAP would be relevant to improve usability, experience, and features on AMAP.

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Human-Centric Decision and Negotiation Support for Societal Transitions

Unlocking the potential of the low-code approach for a more open and innovative higher education system

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Abstract

This paper presents the baseline results of the survey conducted by the LightCode[1] Project Consortium, with the objective of exploring the potential of low-code application development in the field of higher education. The survey included Faculty Members, Higher Education Students and Labour Market Representatives of five European Countries (Austria, Croatia, France, Greece, and Serbia), targeting to address the growing demand for more efficient and accessible digital solutions within education institutions. The survey sought to gauge familiarity with low-code development, and potential challenges and perceived benefits of integrating low-code solutions into the educational domain. As one of the main features of the low-code approach, as well as of the LightCode project, is to provide tools and methodologies that facilitate the development and deployment of applications focused on supporting informed decision-making within organizations, the results presented here aligns with the main topic of the conference as the project will also contribute to enhance the student's employability, which in turns also contributes to empowering societal transitions.

Keywords: Low-Code; Higher Education; Digital Skills; Inclusion; Employability; Erasmus+ Project; LightCode

1. Introduction

In the ever-evolving landscape of software development, organizations are increasingly turning to innovative methodologies to accelerate the delivery of applications and address the growing demand for digital solutions. One such transformative approach gaining widespread adoption is the "Low-Code Development" approach, which represents a departure from traditional coding practices, offering a more efficient and collaborative way to create and deploy software applications [1].

Low-code development involves utilizing visual interfaces, drag-and-drop components, and declarative tools to design, build, and deploy applications. It empowers a broader range of users, including business analysts and citizen developers (non-technical experts), to actively participate in the development process. By minimizing hand-coding, low-code platforms induce a variety of benefits to the business sector and the academia. It significantly reduces development costs and timelines, fostering agility and responsiveness to rapidly changing business requirements. Further on, it should promote innovation and allow businesses of all sizes to compete on the market [2]. Although the low-code platforms are not without problems (e.g. vendor

[1] The LightCode Erasmus+ Project (Nr.2022-1-FR01-KA220-HED-00086863) is co-funded by the European Union. http://www.lightcode-project.eu/

lock-in and maintenance issues [3, 4]), the low-code concept is surely an exciting new software development approach. On these premises, the Erasmus+ LightCode project aims to make higher education more inclusive, shaping opportunities for all students, promoting the development of flexible career paths, and developing skills in line with the intensive development of technology. As more and more organisations and businesses across all sectors are integrating technology into their services, the LightCode project will enhance their employability and students' opportunities in their later professional and social lives [5].

In this short paper, we provide results related to an excerpt of questions from the screening, to offer a data-driven baseline towards: a) the adoption of the LightCode Platform as a didactic tool developed within the project. We try to focus on the support that the results of the project can give to human-centric decision and support applied to societal transitions, having the project stakeholders as active participants, generating empowerment through the use collaborative platforms; and b) the integration of a low-code approach into the Higher Education training curricula, crosscutting students, teachers and labour market representatives' needs. Results are meant to provide a baseline and guidance towards the realization of a master plan for the future, a declaration of our unwavering commitment to empower individuals and organizations with the requisite knowledge and tools to thrive in an increasingly digitalized world.

2. The LightCode Project

The LightCode Project aims at strengthening the digital transformation of higher education through low code. Through this project, we will strive to increase the capacity and readiness of higher education to keep pace with technological developments and market trends. This way, LightCode will manage an effective and innovative shift towards the enhancement of digital skills in every student, regardless of the scientific sector. Such a transition will not only bring benefits to students but will also benefit faculty members with the opportunity to apply modern digital pedagogical methods and to develop and improve their expertise in the use of digital tools. Hence, the LightCode project promotes the development of flexible career paths for all students and creates opportunities for those studying various fields to be more competitive and develop skills in line with the intensive development of technology. Simultaneously, the project promotes gender equality, as it is common for most technology courses to be chosen by male students. The application of pedagogical methods to develop digital skills in most of the university studies, we can create an environment in which all students have digital skills. In consequence, the project aims to promote gender balance in jobs requiring digital and development skills, enhancing also general employability and students' opportunities in their professional and social lives.

The LightCode project approach will promote a student-centered curriculum that is in line with current market needs and technological trends. In this way, skills mismatches can be reduced, and students' learning needs will be more easily met, while the university teaching profession will follow the demanding trends of today's highly digitalised world.

Overall, the LightCode project aims to train faculty members in interdisciplinary approaches and innovative teaching methods and practices, including low-code teaching materials and platforms, forming a more open and innovative higher education system. In order to achieve this main goal, the project will develop: 1) a Teacher's Training Program, so that Faculty Members can learn how to teach the low-code approach to their students, regardless of their field of expertise and study, 2) a low-code course for Higher Education Students, with educational material ready to be used by the Faculty Members 3) a low-code platform, free of charge, for Faculty Members and Students, providing an easy-to-use low-code application development environment.

Specific objectives of the LightCode project:

- To identify the current needs in line with the requirements of the post-covid era, in order to strengthen higher education to provide students of all disciplines with digital skills and tools. To achieve this, detailed research will be carried out to address the existing gaps in the development and usage of digital tools in higher education, as well as at business level.
- To build confidence and empower faculty members to teach digital skills, via offering a training program for them in order to apply low-code training material more easily, while simultaneously further advancing

their professional development towards new technology trends and labor needs.

- To develop an extended range of digital skills for students in order to enable them to apply the knowledge and expertise of the discipline they have studied in the digital environment by developing digital applications and tools. To achieve this, an innovative student-centred curriculum will be developed, which will allow students to exploit the potential of low-level code, without the need for prior knowledge of code development.
- To offer an interactive low-code platform at no cost, that will make application development an easy process. Students will create their own projects and applications through the LightCode platform and will have the opportunity to test more and more of their ideas through our free and open-source tool. This is a great advantage for the platform users, as all such low-code platforms currently available are paid, with monthly subscriptions of demanding amounts.

3. Methodology applied on the Survey Exercise

3.1 Survey Questionnaires

Three questionnaires addressing Faculty Members, Higher Education Students and Labour Market Representatives were prepared and validated by the LightCode Consortium*, which includes universities and enterprises over a range of five European Countries: Austria, Croatia, France, Greece, Serbia). The questions for Faculty Members and those for Students and Labour Market Representatives were mirroring each other: adapted to each stakeholder but targeting the same information. The questionnaires used in the survey were translated and submitted via Google forms, to be filled out completely anonymously. Sampling was a combination of systematic through networks of Faculty Members and Stakeholders, and opportunistic in occasion of university classes and events, targeting 110 Faculty Members, 350 Students and 70 Labour Market Representatives across the participating Countries. Targets were exceeded, with 116 Faculty Members, 442 Students, and 75 Market Labour Representatives, providing responses to the questionnaire. Structure according to gender among faculty members as respondents was quite equal. Also according to gender, approximately 60% of participants among students were female, less than 40% male students, and minority of them wouldn't like to express their gender during survey. Gender structure among stakeholders was different (approximately 41% responses collected from female and 59% collected from male representatives at labour market). Considering respondents structure according to qualifications, repsodents came from diverse academic backgrounds, with a predominant presence in engineering sciences, especially electrical, technical, and mechanical engineering, but also from economics, and other social sciences.

3.2. Focus Group Interviews

Beyond the survey, the project included focus group interviews with selected Faculty Members from the participating countries. Apart from the survey questionnaires, Consortium Partners also organized Focus Groups with 40 Faculty Members (the project target was 35), to discuss in depth some of the questionnaire findings. Interviews were conducted among selected Faculty Members from the 5 countries to consolidate the results of the survey. These interviews aimed to deeper into the survey findings and provide a broad spectrum of perspectives.

The focus group interviews were structured to facilitate in-depth discussions, allowing participants to share their experiences and insights regarding low-code development in higher education. These sessions were instrumental in revealing the nuances of faculty members' attitudes towards low-code, such as their enthusiasm for new pedagogical approaches, concerns about implementation, and the perceived impact on student engagement and career readiness.

4. Results

The survey results revealed several key insights:

- Faculty members recognized the potential of low-code application development to enrich the learning experience, suggesting the use of interactive tools in teaching.

- Students showed interest in acquiring low-code skills, aligning with the evolving job market requirements.
- Labour Market Representatives emphasized the growing demand for low-code skills in various industries.

The questionnaires were meticulously crafted to cover a broad spectrum of topics related to low-code application development. For Faculty Members, the focus was on their awareness, interest in incorporating low-code into teaching, and the perceived benefits and challenges of such integration. For Students and Labour Market Representatives, the questions aimed to assess their familiarity with low-code, the perceived relevance of low-code skills in their respective fields, and their interest in low-code training opportunities. This comprehensive approach ensured a well-rounded understanding of the perceptions and needs across different stakeholder groups.

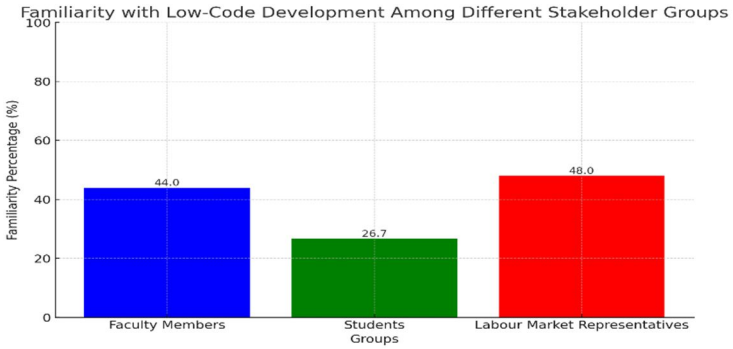

Figure 1: Familiarity with Low-Code Development Among Different Stakeholder Groups.

Figure 1 represents the familiarity with low-code development among three groups: Faculty Members, Students, and Labour Market Representatives. Each bar corresponds to one of the groups, depicted in different colours (blue for Faculty Members, green for Students, and red for Labour Market Representatives), and displays the percentage of familiarity. The chart clearly illustrates the varying levels of familiarity with low-code development across these different stakeholder groups.
Figure 2 visualizes the key themes from focus group interviews. The chart represents the emphasis or importance given to various topics discussed, including Training Need, Interest & Awareness, and Curriculum Implementation. Each topic is represented by a bar in different colours (orange for Training Need, purple for Interest & Awareness, cyan for Curriculum Implementation), with their respective estimated values based on the focus group discussions. This figure effectively summarizes the main themes and highlights the areas of major interest and discussion from the focus groups.

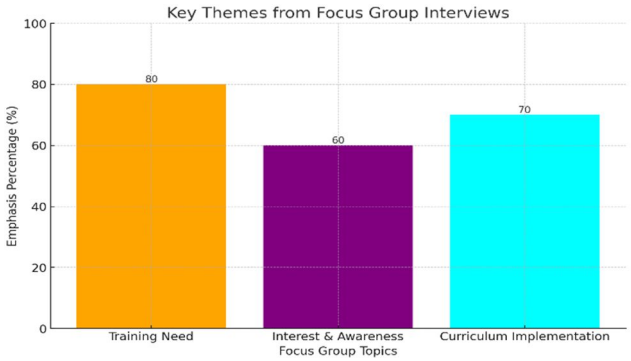

Figure 2: Key Themes from Focus Group Interviews.

The survey responses across all countries revealed varying levels of awareness and understanding of low-code application development among faculty members. 56% of the respondents have never heard of the term

“low-code application development”. However, among those who were familiar with it, demonstrated a reasonably good understanding of the concept. Teaching experiences related to low-code approaches were relatively limited across all countries, but the potential of low-code application development to enrich the learning experience is acknowledged. Recognizing the practical skills gap in the job market, faculty members believe that teaching low-code in higher education equips students with valuable industry-relevant skills. This alignment with industry trends enhances graduates' employability and competitiveness.

The analysis of university students' perceptions of low-code usage and expectations provides nuanced insights into their familiarity with the technology, their prior experiences, and their views on its potential. Although most students across all countries (73,3%) have never heard of the term “low-code”, after understanding the concept, they perceived it as an opportunity to quickly turn their ideas into reality and develop practical skills that could benefit them academically and professionally. Almost 58% of the students would be interested in receiving training in low-code application development.

Although 52% of the labour market representatives (Stakeholders) across partner countries were not familiar with the term “low-code”, they generally recognized the potential benefits of low-code development, particularly its ability to lower entry barriers, reduce costs, and enhance agility. These advantages align with the broader goal of simplifying and accelerating the software development process. However, stakeholders also voiced concerns about security risks, platform limitations, and the ownership of source code.

The survey responses from all participating countries revealed a varied level of awareness and understanding of low-code application development among different groups.

Faculty Members:

- Awareness: 56% of the respondents were unfamiliar with the term "low-code application development." Those familiar with it showed a good understanding of the concept.
- Experience in Teaching Low-Code: Teaching experiences with low-code approaches were limited, but the potential for enriching the learning experience was widely acknowledged.
- Perception of Low-Code's Role in Education: Faculty members see teaching low-code as a way to equip students with industry-relevant skills, addressing the practical skills gap in the job market and enhancing graduates' employability and competitiveness.

University Students:

- Familiarity with Low-Code: A significant portion (73.3%) had not heard of "low-code" before the survey. Upon introduction to the concept, they recognized it as a means to turn ideas into reality and develop practical skills beneficial for both academic and professional settings.
- Interest in Training: Approximately 58% expressed interest in receiving training in low-code application development, highlighting a keenness to learn and adapt to new technologies.

Labour Market Representatives:

- Awareness and Perception: 52% were not familiar with "low-code." However, those aware acknowledged the potential benefits, particularly in lowering entry barriers, reducing costs, and enhancing agility.
- Concerns: Noted concerns included security risks, platform limitations, and issues around the ownership of source code, reflecting a need for addressing these aspects in the development and adoption of low-code platforms.

Interpreting the Results:

- Overall Perception: The results reflect a general lack of awareness but a positive reception upon understanding the concept of low-code. This indicates a significant opportunity for educational initiatives to raise awareness and provide training in low-code development.
- Potential for Integration in Education: The responses suggest a fertile ground for integrating low-code in educational curricula, aligning with industry needs and enhancing student skill sets for future job markets.
- Need for Addressing Concerns: The concerns raised by labour market representatives underscore the importance of ensuring security, flexibility, and clarity in ownership rights in low-code platforms.

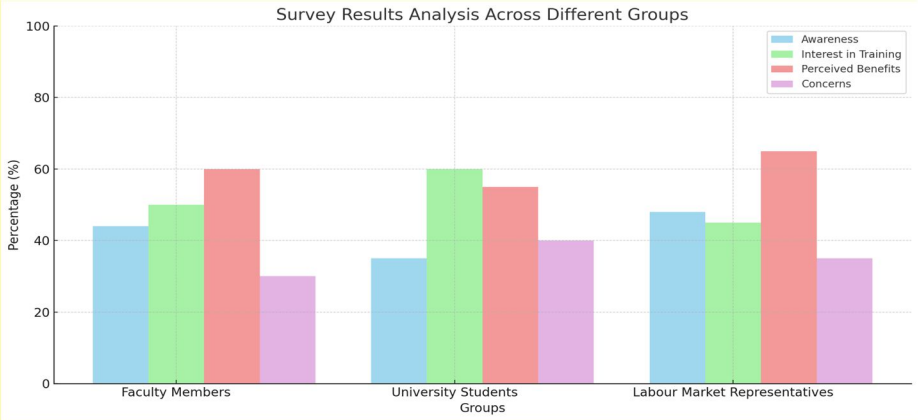

Figure 3: Survey Results Analysis Across Different Groups.

Figure 3 presents the survey results analysis across different groups: Faculty Members, University Students, and Labour Market Representatives. The chart encompasses various aspects of the survey results: Awareness, Interest in Training, Perceived Benefits, and Concerns. The survey results underscored a significant gap in awareness about low-code development across all groups, with a notable disparity between the faculty members' and students' familiarity with the concept. Despite this, there was a clear recognition of the potential benefits of low-code in education and the broader job market. Faculty members and students alike saw low-code as a tool for bridging the skills gap, while Labour Market Representatives viewed it as a means to innovate and streamline processes.

The focus group discussions highlighted the following aspects:

- The need for enhanced training and resources in low-code development for faculty and students.
- The diversity in the level of interest and awareness about low-code across different academic disciplines.
- Discussions on the practical implementation of low-code in the curriculum and its potential impact on student engagement and employability.

These insights complement the survey findings, painting a more comprehensive picture of the current state and future potential of low-code application development in higher education settings.

5. Conclusions

This paper has highlighted the profound impact of low-code development on not only the technical aspects of application creation but more importantly on the empowerment of users across diverse domains. Low-code platforms empower a broader spectrum of individuals extending beyond traditional developers to include business analysts, subject matter experts, and citizen developers. This democratization of software development enhances the inclusivity of the process, allowing those closest to business needs to actively participate in application creation. Another important aspect to be considered is that low-code development fosters collaboration between IT professionals and business users. This collaborative approach ensures that applications are not only technically robust but also aligned with the evolving needs of end-users. The synergy between different stakeholders results in innovative solutions that directly address real-world challenges.

By placing users at the centre of the development process, low-code platforms enable the creation of applications that resonate with the end-users. The intuitive nature of visual development interfaces coupled with user feedback loops ensures that applications are not only functional but also user-friendly, enhancing the overall user experience. Building upon this, insights gathered from faculty members across five partner countries — France, Greece, Croatia, Serbia, and Austria — reveal both opportunities and challenges in implementing low-code application development in higher education. These include enhanced student learning and engagement, streamlined administrative processes, support for research activities, and alignment with industry demands. However, challenges such as awareness and familiarity, varying levels of interest, and diversity in training methods must also be addressed.

In summary, external stakeholders of the project composed of faculty members, students, and companies' representatives from the European Countries (Austria, Croatia, France, Greece, and Serbia) have allowed the authors to build up on their experiences and feedback a parallel screening to highlight the gaps in higher education related to low-level code so that efforts can be further made to enhance the potential of the low-code approach for a more open and innovative higher education system. By addressing these challenges and capitalizing on opportunities, institutions can harness the power of low-code to enhance teaching, research, and administrative processes, while equipping students with valuable skills for the future job market. The findings from the LightCode Project survey and focus groups reveal a landscape ripe for the integration of low-code development into higher education. Addressing the awareness gap and providing targeted training can empower students and faculty alike, aligning educational outcomes with industry demands. The potential of low-code to revolutionize learning, research, and administrative processes in higher education institutions is evident, promising a more inclusive and innovative future.

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24th International Conference on Group Decision and Negotiation &
10th International Conference on Decision Support System Technology
Human-Centric Decision and Negotiation Support for Societal Transitions

Selection of technical improvements in product design

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Abstract

Product developers might think that the products they offer will be aligned with their customers' expectations, but this is often not the case. From the practical point of view, the most important information for technical teams when designing a product is to be aware of the contribution of each technical requirement (TR) to customer satisfaction, which is the purpose of the House of Quality (HoQ) tool. During the product development phase, it is not possible or desirable to improve all TRs' performances to obtain a better product due to resource constraints. In the face of this, the goal should be to select an efficient portfolio of TRs' measures of performance improvement for a product. The main objective of this paper is to develop a portfolio decision analysis model to improve a product configuration considering different TRs' improvement measures. We propose using the decision support system PROBE to identify all efficient portfolios and depict the respective Pareto frontier within a given cost range. To implement the model, we present an illustrative example concerning an operating room's door for hospitals.

Keywords: House of Quality; product design; resource allocation; technical performance; PROBE

1. Introduction

Customer satisfaction with product design is a critical factor for product success (Chen and Chuan 2010; Sharma and Rawani 2009). Quality Function Deployment (QFD) is a management approach for developing customer-oriented products (Akao 1990; Parezanović et al. 2019; Li and Zhang 2021). The House of Quality (HoQ) is the primary tool of QFD used in product development. It starts by identifying Customer Requirements (CRs) and their associated Technical Requirements (TRs), creating the relationship between CRs and TRs to weigh the TRs.

The TRs' weights are critical parameters in the HoQ because of their impact on resource allocation and final decision-making in product design (Wang and Chin 2011). These weights are calculated using the CRs' weights and the measures of the relationships between CRs and TRs, which also turns the latter into determinant elements for that purpose. Sanaz et al. (2023) proposed a new approach to weighing CRs and TRs, using the MACBETH procedure and software, and assessing the relationship matrix parameters by considering the effect of a *swing* (i.e., an improvement) in a TR on the improvement of a CR.

In product design, designers must decide how to select an efficient combination of different TRs' performances (measures) to improve a product in face of scarce resources. Typically, there are numerous possible combinations of measures of performance improvement on the several TRs, which turns the resource allocation to product development into a hard problem to solve. Other factors that might also increase the complexity of portfolio selection are possible interrelationships and synergies among the TRs, which in the HoQ are depicted on the *roof* of the House. This information is essential to product designers for selecting the TRs to improve and the extent to which they should be improved to obtain a better product. Previous studies have considered the TRs' interrelationships as correlation measures (Iqbal et al., 2016). In this paper, we first detect if there are any interrelationships between TRs, and then we investigate the joint effect of combining different performances of two TRs at each time.

The question that arises is how to choose a portfolio of TRs' performance measures to increase customer satisfaction under a given budget. In this paper, we apply the decision support system (DSS) PROBE (Portfolio Robustness Evaluation) (Lourenço et al., 2012) to identify the complete set of efficient portfolios that comply with all the identified constraints within a given portfolio cost range and allow users to analyse, in-depth, the robustness of selecting a proposed portfolio. Furthermore, the DSS considers possible synergies and interactions between TRs. As a result, PROBE identifies all the efficient portfolios for any given range of costs and depicts them in a cost-versus-benefit graph.

The remainder of this paper is organised as follows. Section 2 implements a PROBE model to find efficient portfolios of TRs' performance improvement measures within a given cost range, based on a constructed example of an operating room's door for hospitals. It starts by defining the model's parameters in Section 2.1. It adds some required constraints to the model in Section 2.2. Section 2.3 shows the set of efficient portfolios. Section 3 discusses the applied approach. Finally, Section 4 presents the conclusion of the paper and identifies some avenues for future research.

2. Methodology

In this section, we implement a PROBE model with an illustrative example of a required operating room's door for hospitals. The TRs of an operating room's door are identified as associated with the customers' needs who use the door frequently, such as doctors, nurses, and other auxiliary staff. Table 1 shows the TRs and their associated descriptors of performance.

Table 1. Technical requirements for the operating room's door

Technical requirement	Descriptor of performance
TR_1: Easiness of the door operation	*Constructed descriptor*
TR_2: Hold-open time	The time the door is kept opened (seconds)
TR_3: Opening speed	The speed of opening the door (cm/s)
TR_4: Materials usage	The material used for the door maintenance
TR_5: Width of the door	The width that is available to pass through when the door is opened (cm)

2.1. Defining the model parameters

Improving TRs' performances with a scarce budget is a demanding decision-making problem that requires balancing multiple benefits against costs, even if there are no other constraints and no cost or benefit interdependencies. In the example of the operating room's door for hospitals, considering all TRs in Table 1, different performances may be improved. Assume that all TRs' performances are anchored in two references for the door, the *current* performance, and a *good* performance (i.e., a significant attractive performance), to which were assigned 0 and 100 value units, respectively. Note that in this model we assume that the *current* door performances are worth 0 value units because there is no added benefit in leaving the door unchanged. A product designer would be interested in identifying a portfolio of TRs' improvements that maximises the overall benefit (i.e., customer satisfaction) while respecting the budget constraint. the MACBETH method (Bana e Costa et al., 2012), as exemplified in Sanaz et al. (2023).

Table 2 shows the TRs' performance levels, and their related benefit values and costs. Each TR's performance level is depicted as L_{jl}, where j is the TR index, and l is the associated level. The benefit value of each performance is obtained with the MACBETH method (Bana e Costa et al., 2012), as exemplified in Sanaz et al. (2023).

Table 2. TRs' performance levels and their associated benefit values and costs

TR	Performance	Benefit value	Cost (in €)
TR_1	The door opens…		
	$L_{1,4}$: Automatically using a proximity sensor = *good*	0	50
	$L_{1,3}$: By pressing a button	36	140
	$L_{1,2}$: By entering a code	64	160
	$L_{1,1}$: Manually by pushing it = *current*	100	200
TR_2	The time the door is kept opened is…		
	$L_{2,3}$: 30 s = *good*	0	50
	$L_{2,2}$: 20 s	50	110
	$L_{2,1}$: 10 s = *current*	100	140
TR_3	The speed of opening the door is…		
	$L_{3,3}$: 100 cm/s = *good*	0	50
	$L_{3,2}$: 50 cm/s	50	85
	$L_{3,1}$: 25 cm/s = *current*	100	110
TR_4	The material used for the door maintenance is…		
	$L_{4,3}$: Stainless steel = *good*	0	50
	$L_{4,2}$: Aluminium	56	100
	$L_{4,1}$: Galvanized steel = *current*	100	150
TR_5	The width that is available to pass through when the door is opened is…		
	$L_{5,3}$: 200 cm = *good*	0	50
	$L_{5,2}$: 180 cm	57	160
	$L_{5,1}$: 160 cm = *current*	100	180

The weight of each TR is obtained as the aggregation of the associated CRs' weights and the corresponding relationship matrix parameters, as proposed by Sanaz et al. (2023). Table 3 shows the TR's weights.

Table 3. TRs weights

w_{TR1}	0.27
w_{TR2}	0.21
w_{TR3}	0.12
w_{TR4}	0.20
w_{TR5}	0.20

To perform a portfolio analysis with PROBE, we start by creating a value tree with all the operating room's door TRs, as shown in Figure 1.

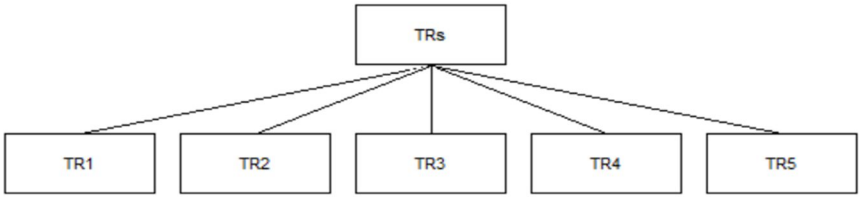

Figure 1. TRs' value tree

Then, we input all plausible performances assigned to each TR. For instance, the performances of $L_{2,1}$, $L_{2,2}$ and $L_{2,3}$ are associated to TR_2. Next, the benefits and costs of all performance levels in Table 2 are inputted into the DSS. The overall benefit value of a given portfolio of performance measures is calculated as the weighted sum of the selected TRs levels' value scores.

2.2. Adding constraints to the model to address dependencies and synergies

We added some constraints to the model to define interrelationships between performances of two different TRs (see Figure 2):

- $L_{1,4}$ (performance level 4 of TR_1) depends (D) on $L_{3,3}$ (performance level 3 of TR_3), thus $L_{1,4}$ cannot be selected unless $L_{3,3}$ is also selected.
- $L_{4,1}$ (performance level 1 of TR_4) is mutually exclusive (×) with $L_{1,1}$ (performance level 1 of TR_1), thus $L_{4,1}$ and $L_{1,1}$ cannot be selected for the same portfolio.
- $L_{5,3}$ (performance level 3 of TR_5) is mutually exclusive (×) with $L_{3,1}$ (performance level 1 of TR_3), thus $L_{5,3}$ and $L_{3,1}$ cannot be selected for the same portfolio.

	$L_{1,1}$	$L_{1,4}$	$L_{3,1}$	$L_{3,3}$	$L_{4,1}$	$L_{5,3}$
$L_{1,1}$						
$L_{1,4}$				D		
$L_{3,1}$						
$L_{3,3}$						
$L_{4,1}$	×					
$L_{5,3}$			×			

Figure 2. TRs' interrelationships

After defining the interrelationships, the design team investigated possible synergies between different TRs' performances. To have a synergy between the costs or the benefits, it is assumed that there are two performances of different TRs that allow the joint benefit values (or joint cost) to be different from the sum of their individual benefits (or costs). Therefore, their joint benefit value may be worth more (or less) than the sum of the benefits of these TRs' performance levels, and the same may be considered for the costs. In the operating room's door example, some synergies were identified: between the costs of $L_{5,1}$ (performance level 1 of TR_5) and $L_{3,3}$ (performance level 3 of TR_3), and between $L_{5,1}$ (performance level 1 of TR_5) and $L_{3,2}$ (performance level 2 of TR_3) with costs savings of €55 and €56, respectively.

To complete the model formulation in PROBE we need to add five other constraints because it must select only one performance level of each TR.

2.3. Performing portfolio analysis

After inserting a lower and an upper cost bound for the portfolios, PROBE is able to identify the efficient frontier for a portfolio cost range. In our example, the lower and upper costs were anchored to €400 and €700, respectively. For this cost range, PROBE identified the 9 efficient portfolios shown in the graph in Figure 3. To select a portfolio of TRs, designers decided to choose a door that does not exceed €550. With this indicative budget, the proposed efficient portfolio is the one with a benefit score of 71.2 and a cost of €545 (see the red star in Figure 3), which includes the TR's performance levels that are highlighted in red in Table 4.

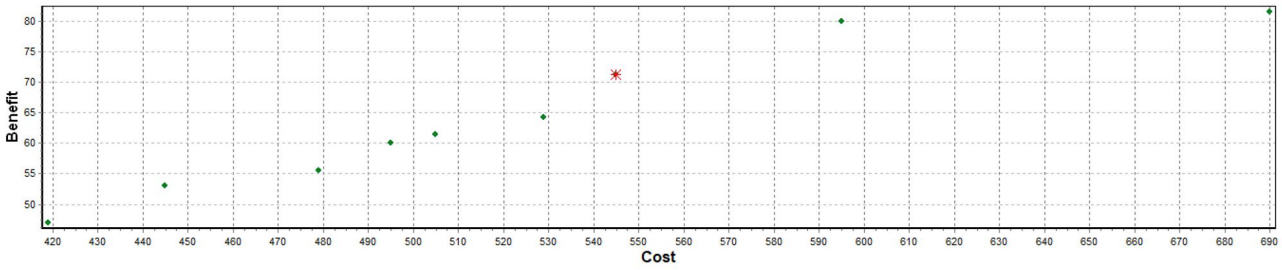

Figure 3. Efficient portfolios

Table 4. The proposed portfolio

TR	Performance
TR_1	The door opens… $L_{1,4}$: Automatically using a proximity sensor = *good* $L_{1,3}$: By pressing a button $L_{1,2}$: By entering a code $L_{1,1}$: Manually by pushing it = *current*
TR_2	The time the door is kept opened is… $L_{2,3}$: 30 s = *good* $L_{2,2}$: 20 s $L_{2,1}$: 10 s = *current*
TR_3	The speed of opening the door is… $L_{3,3}$: 100 cm/s = *good* $L_{3,2}$: 50 cm/s $L_{3,1}$: 25 cm/s = *current*
TR_4	The material used for the door maintenance is… $L_{4,3}$: Stainless steel = *good* $L_{4,2}$: Aluminium $L_{4,1}$: Galvanized steel = *current*
TR_5	The width that is available to pass through when the door is opened is… $L_{5,3}$: 200 cm = *good* $L_{5,2}$: 180 cm $L_{5,1}$: 160 cm = *current*

3. Discussion

This paper proposes using PROBE to identify efficient portfolios of TRs' performances to help designers in product improvement. A created example with a hospital operating room's door was used to explain how this can be done. First, defining the parameters of the model such as TRs' weights (Table 3), benefit value scores of each TR's performances obtained from the HoQ approach presented by Sanaz et al. (2023), and their associated costs (Table 2). Second, adding the necessary constraints to model different types of interrelationships among performances of different TRs, such as mutual exclusivity and dependency. Synergies between performance levels were also considered. In the example presented, there were two synergies: a synergy between the cost of $L_{5,1}$ (performance level 1 of TR_5) and $L_{3,3}$ (performance level 3 of TR_3) with a cost saving of €55, and another between the cost of $L_{5,1}$ (performance level 1 of TR_5) and $L_{3,2}$ (performance level 2 of TR_3) with a cost saving of €56. Note that these synergies only take effect in the DSS when both levels are selected for the same portfolio.

A last constraint was defined to force PROBE to select exactly one performance level of each TR into the portfolios within the cost range of €400 and €700. The proposed efficient portfolio for an indicative budget of €550 includes the performances $L_{1,4}$, $L_{2,3}$, $L_{3,3}$, $L_{4,2}$ and $L_{5,1}$ (see Table 4) with an overall benefit value of 71.2 units and a cost of €545.

4. Conclusion and future work

Identifying a portfolio of technical measures of a product is challenging as the TRs have several performance levels and designers must decide how to efficiently combine them under a resource constraint.

The presented approach may be used to aid a design team in the difficult task of selecting a portfolio of measures in the presence of limited resources, multiple TRs, and different interactions. PROBE could identify all efficient portfolios and depict them in a cost versus benefit graph within a given portfolio cost range and allow the user to perform an in-depth interactive analysis of the robustness of selecting a proposed portfolio when uncertainty is also defined in the model.

In the present paper, we identified the efficient portfolios of improved TRs' performances with a hospital operating room's door example. From the HoQ, we also considered the interrelationships among TRs (the so-called roof of the HoQ). These interrelationships are performance-based and thus depend on the combination of different performances of distinct TRs.

PROBE is a useful tool for portfolio selection of TRs considering discrete performance levels, but not for continuous performances. To deal with the latter requires creating a multi-objective tool, which would involve dealing with additional complexities derived from the fact that the interrelationships between levels are performance-dependent.

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Human-Centric Decision and Negotiation Support for Societal Transitions

A GIS-based Decision Support System for Natural Gas Distribution Planning

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Abstract

The ongoing restructuring of the energy sector, driven by the convergence of new technologies and increased demand, requires strategic adaptations. In this changing scenario, natural gas is emerging as a versatile competitor to various alternative fuels. However, effectively planning its utilization is challenging due to the numerous influencing factors. One of the biggest challenges, which directly affects stakeholders, is the decision of how to invest in a portfolio of network expansion projects so that the company ensures continuity of service with due remuneration for the investment made. To manage this complexity, our study introduces a GIS-based multicriteria decision support system for portfolio selection within natural gas companies. The proposed multicriteria model uses an additive aggregation methodology that includes a benefit-to-cost ratio-based approach. The model is integrated with a Geographic Information System (GIS), providing companies with a comprehensive framework that combines spatial and multicriteria analysis. Consequently, this integrated approach enables companies to strengthen their strategic decision-making processes, ultimately achieving efficient and informed results.

Keywords: natural gas; multicriteria; portfolio; GIS; DSS.

1. Introduction

The energy sector has transformed due to rising demand and the availability of new technologies. Natural gas is a versatile fuel that has the potential to compete with almost all other alternative fuels in the transition to a low-carbon energy matrix. In Brazil, the use of natural gas has increased due to the greater supply resulting from the exploration of fossil fuels in deep waters (pre-salt). However, the natural gas market is considered less developed than the international natural gas market in terms of seeking efficiency, cost reduction, continuous process improvement, corporate social responsibility actions, risk reduction, and competitiveness concerning other energy sources.

When observing the strategic and operational planning processes, companies that work with natural gas have been faced with several difficulties in presenting satisfactory and efficient results, which meet different interests. One of the biggest challenges, which directly affects stakeholders, is the decision of how to invest in a portfolio of network expansion projects so that the company ensures continuity of service with due remuneration for the investment made.

Brazil plans to expand to increase natural gas consumption and competitiveness in the sector while meeting the demands of its public and private stakeholders (Baldin de Lacerda et al., 2021). Planning the use of natural gas is a significant challenge due to the multiple criteria involved.

Faced with these challenges, this study proposes a multicriteria method with a cost-benefit approach for portfolio selection to define potential natural gas distribution network expansion projects. The model developed considered a decision rule to meet the dynamics of the natural gas distribution network construction

business model since a new network must be connected to an existing network. In addition, the research considered integrating the multi-criteria model with a Geographic Information System (GIS), providing data and business knowledge to enable the standardization and formalization of the decision-making process in a natural gas distribution company in Brazil, in an informed, interactive, and flexible way.

2. Background

The use of GIS for decision support has resulted in a Spatial Decision Support System (SDSS), which is an interactive computerized system based on Geographic Information and Spatial Analysis for decision support (Leake & Malczewski, 2000). The SDSS needs to present mechanisms for inputting spatial data, provide its representation, include analytical techniques for spatial analysis, and provide data output in spatial forms, such as maps (Keenan & Jankowski, 2019).

(Malczewski, 2006) notes that relevant papers on GIS integration applications began to be published in the 1990s due to the increased spread of geographic information systems and the development of user-oriented technologies. This led to the application of GIS to various approaches, including spatial decision problems.

Since 2000, there has been a substantial increase in the publication of articles on this subject. This phenomenon can be attributed to several factors, but it is mainly due to the importance of analysis and decision support as a fundamental element in GIS science, as well as the availability of software that includes complete modules for multicriteria decision support methods in GIS (Malczewski, 2006).

According to (Keenan & Jankowski, 2019), 70% of the papers published between 2015 and 2020 utilized AHP, OWA, and other MAVT (Multiattribute Value Theory) methods. The most notable examples of complete integrations between MCDM/A and GIS are applications of the ELECTRE TRI multi-criteria method in both free and paid software. These integrations have employed various programming strategies, including creating plug-ins in Python, C, and VBA programming (Keenan & Jankowski, 2019).

While there have been many studies on the integration of GIS and MCDM/A, there are still limitations to these combinations. There is also a gap in the development of Spatial Multicriteria Decision Support Systems that focus on integrating a multicriteria method with the cost-benefit approach in a GIS environment. Furthermore, there are no studies specifically focused on determining a portfolio of infrastructure projects for distributing natural gas in the area. Therefore, conducting a study in this context is highly relevant.

3. Methodology

The study is based on the framework of twelve steps proposed by De Almeida & Roselli (2022) to define potential projects for expanding natural gas distribution networks (Figure 1). For the problem context, a set of 45 distribution network alternatives (A = { A1, A2, …, A45}) was considered to be selected within one year, which exceeded the capacities of physical, technical, and financial resources from a natural gas company in Brazil.

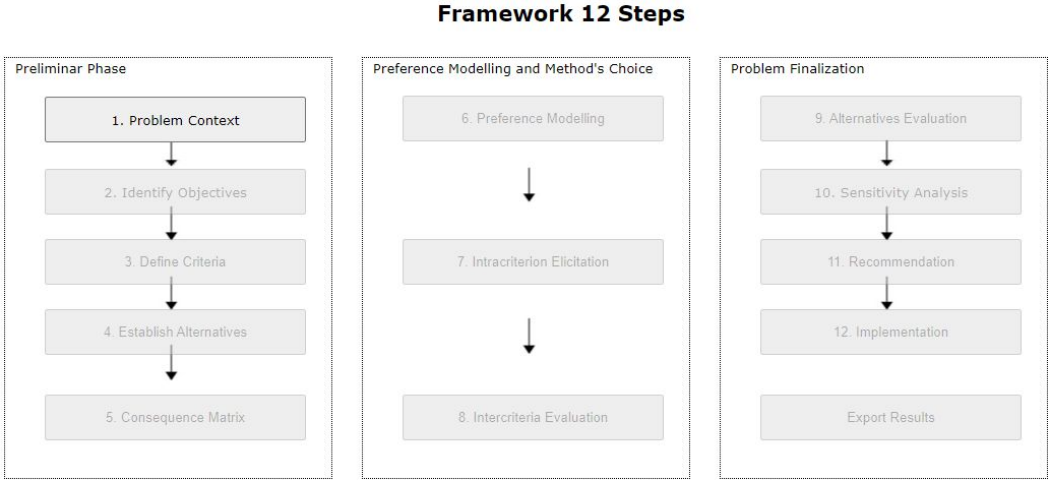

Figure 1: Steps of the Methodology. Source: De Almeida & Roselli (2022)

Figure 2 shows steps 1, 2, and 3 from the study. In Step 1 we defined the problem context and the actors of the decision problem. In Step 2 we identified the objectives and in Step 3 we established the criteria of the problem.

1. Problem Context

A set of distribution network alternatives to be selected within a period of one year, which exceeded the capacities of physical, technical and financial resources.

1. Characterize the decision-maker and the actors

Actor:	Description:
Decision Maker	Planning management
Analyst	Researchers
Client	Board of Executive Directors
Expert	Project Analyst

2. Identify objectives

Definition of the project portfolio.

3. Establish criteria

Criteria	Description	Objective
C1	Payback	Minimize
C2	Internal Rate of Return	Maximize
C3	Volume m3	Maximize
C4	Urgency	Maximize
C5	Compromise	Maximize
C6	Risk	Minimize

Figure 2: Steps 1, 2, and 3 from the Methodology.

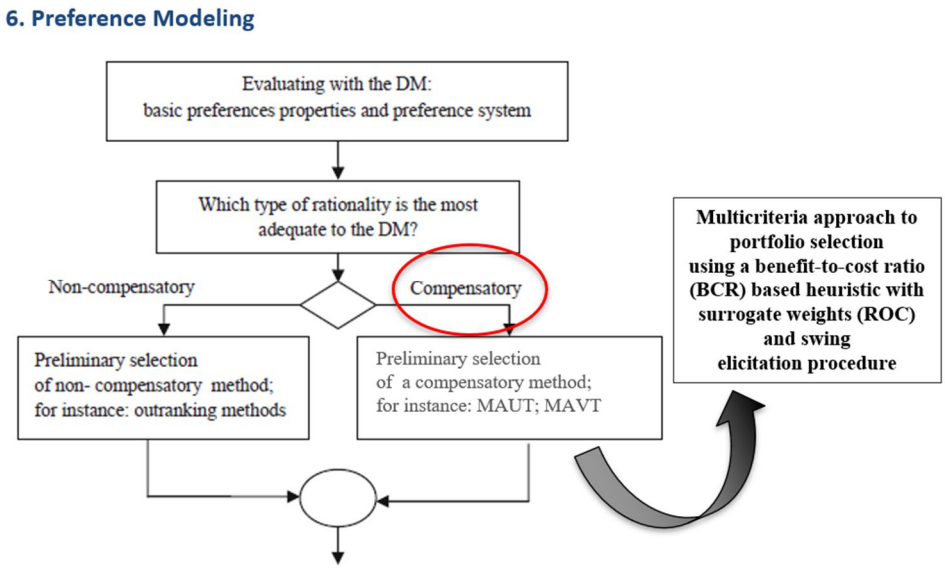

Figure 3: Preference Modeling Step. Adapted from De Almeida & Roselli (2022).

In the preference modeling step, we defined the multicriteria method for the problem, as shown in Figure 3. Steps 7 to 12 are performed in the system that was developed, called NexGas and it involves the intracriterion elicitation, the intercriteria evaluation, the alternatives evaluation, the sensitivity analysis, the recommendation and implementation

Next, the design and architecture of a Multicriteria Spatial Decision Support System (MC-SDSS) were

developed. The system can receive data from other information systems and users, process it using multicriteria analysis to define the project portfolio, and provide robust results to guide the company's investments. Figure 4 shows the system components.

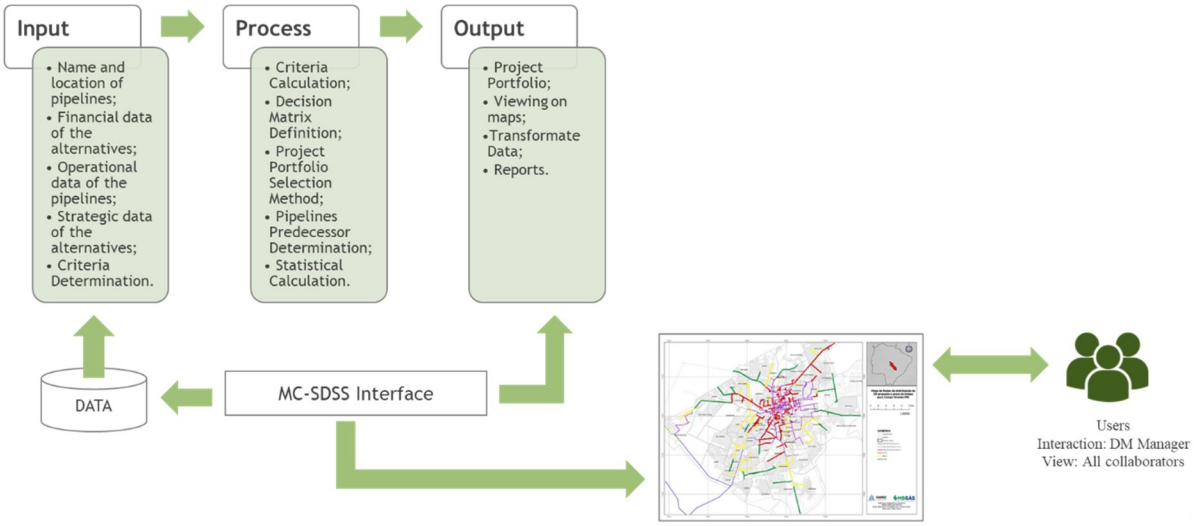

Figure 4: System components

The first stage of the system involves the natural gas distribution pipelines and their financial, operational, and strategic data, as well as the determination of the criteria. The second stage involves calculating the criteria for the alternatives and defining the decision matrix for developing the project portfolio selection model. The criteria defined for the model include payback, internal rate of return (IRR), volume, urgency, service commitment, and project risk. The model's alternatives are the natural gas distribution networks. For the preference modeling, a multicriteria approach to portfolio selection using a benefit-to-cost ratio (BCR) based heuristic with surrogate weights (ROC) and swing elicitation procedure was used.

The distribution network is formed by taking into account the existing connections in the network. The result may show a first alternative without a direct connection to the existing natural gas distribution network. However, the entire network must be fully connected, and expansion without an existing network interconnecting with the chosen alternative is not possible. Finally, statistical calculations are performed to analyze and standardize the information.

The output of the third stage presents the project portfolio in the form of a table ranking and a map of the distribution network, with a didactic visualization of new sections to be implemented. Other outputs are transformed data, such as the definition of the natural gas volume to be covered by the expansion, and reports for management analysis. The data is entered into the MC-SDSS interface via the users' company information systems, where the decision-maker is responsible for interacting with the multicriteria method in defining the portfolio and the employees are only allowed to view the results.

4. Results

The developed methodology was tested for the expansion of natural gas distribution pipelines in a city in Brazil. The adaptation of the model must make it possible to integrate it with any GIS environment, as in the case of this study, where the company already has a GIS, called Prospect. To this end, an Application Programming Interface (API) named JSON was used to exchange data and information between the GIS and the MCDM/A.

The natural gas distribution company developed the Prospect system, a management information system,

using JavaScript and a Google Maps interface. Figure 5 shows the development of the Multicriteria Spatial Decision Support System.

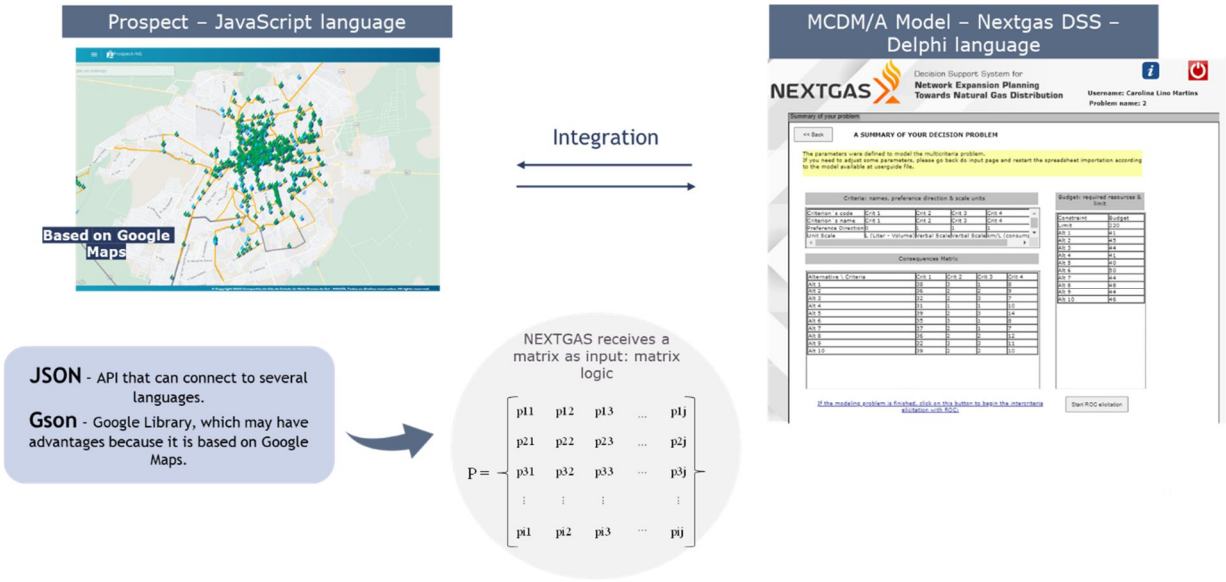

Figure 5: Multicriteria Spatial Decision Support System

About the GIS-based approach, the research is conducted through a Decision Support System (DSS), called NextGas. The GIS-Based Multicriteria Decision Support System starts from the possibility of integrating multicriteria methods that define the portfolio, considering geographic information, favoring, and streamlining, through a user-oriented interface, decision making. Finally, the interface of the developed system is illustrated in Figures 6 and 7.

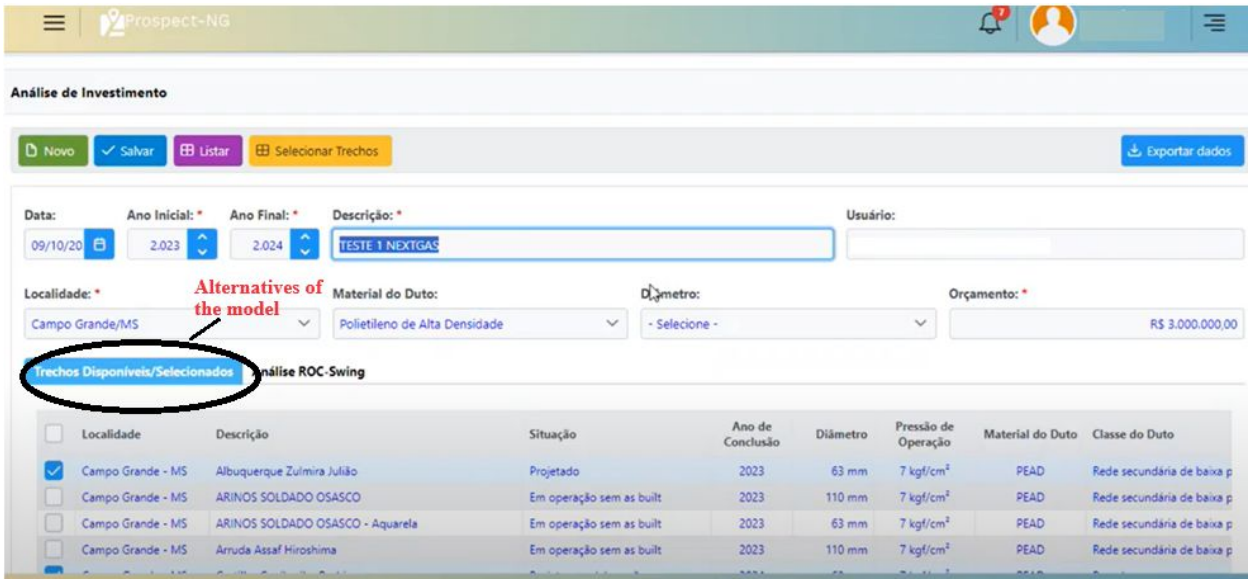

Figure 6: Prospect-NextGas initial interface

Figure 6 shows the initial interface of the system, where it is possible to select the alternatives of the model. 45 potential alternatives for the expansion of the distribution network make up the set of alternatives, where A = {A1, A2, ..., A45} with a budget limitation of $ 3,000,000.00. Each alternative represents the name of a street.

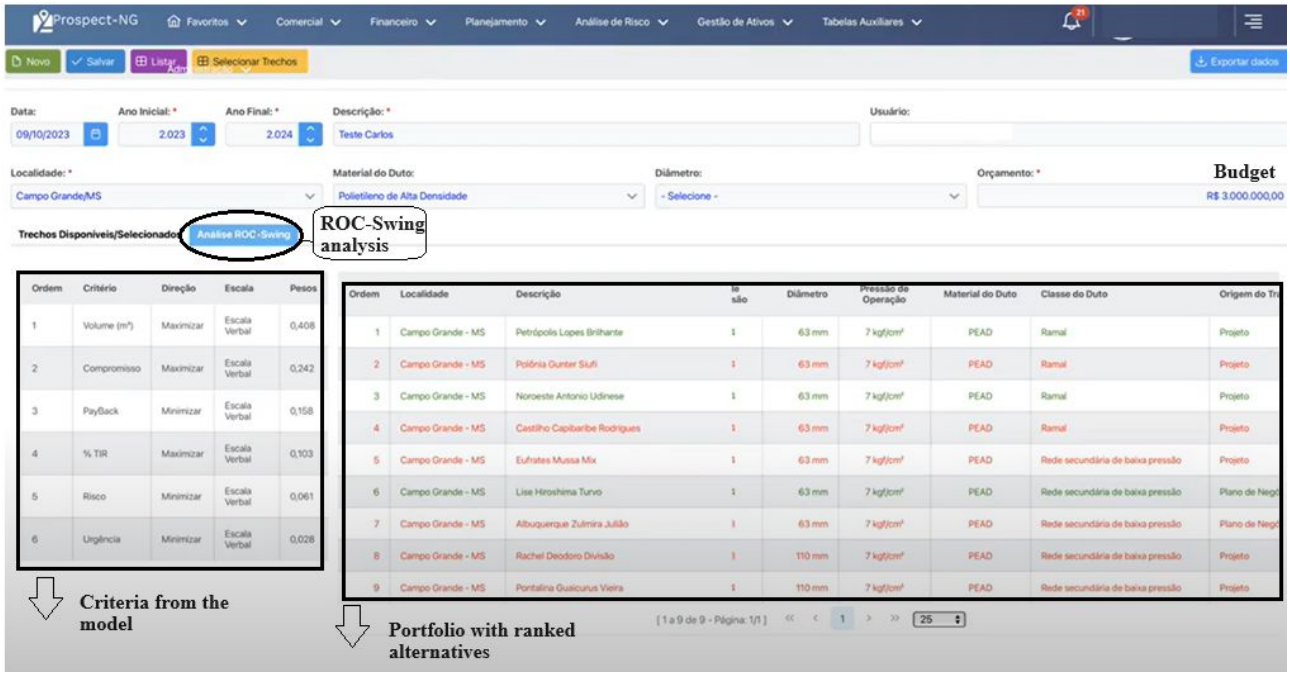

Figure 7: Interface with Prospect-NextGas application results

Figure 7 displays the results of the ROC-SWING analysis. The recommended portfolio is presented with ranked alternatives, where green indicates selected alternatives and red indicates rejected ones. The selection of the portfolio is dependent on additional constraints imposed by the gas distribution system. If there is no existing network interconnecting with the chosen alternative, expansion is not possible. Therefore, even if some alternatives rank highly, they may not be selected due to these constraints. This is the case with alternatives 2, 4, and 5, as shown in Figure 7.

The selected alternatives were validated by the DM by the demonstration of the result obtained. According to the DM, the portfolio that was created reflects its preferences; in other words, the alternatives chosen for the natural gas distribution network development, in DM's opinion, represent the goals of the company that is the subject of the study.

The system has several advantages, including a faster and more objective preference elicitation procedure, and the use of a BCR analysis to generate portfolios based on rankings, which allows companies to establish a course of action and define a long-term business plan. Additionally, the system employs a decision rule that requires the entire network to be fully connected, making expansion without an existing network interconnecting with the chosen alternative impossible.

5. Conclusions

The versatility of natural gas makes it a potential competitor to almost all other alternative fuels. However, the challenge of consolidating this fuel as a pillar of the clean energy transition with efficient planning of its use is immense, as it depends on multiple economic, operational, and regulatory variables. To meet all stakeholder interests, support and improve the decision-making process of natural gas distribution companies, and increase the social reach of natural gas, this study proposed the development of a multi-criteria decision system integrated with geographic information to define a portfolio of natural gas distribution network expansion projects applied to a real case. At the end of the study, we were able to develop a decision model that took into account, among other criteria, the number of consumers impacted by the expansion of the distribution network, which allows access to Natural Gas to be facilitated for a greater number of consumers.

The main results of the research led to the development of a new model, in which a systemic mathematical method was incorporated into the decision-making process, allowing financial and strategic objectives to be addressed in the important decision to identify a portfolio of projects for expanding the natural gas network.

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Human-Centric Decision and Negotiation Support for Societal Transitions

Network attacks prediction using set of machine learning models for supporting decision making

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Abstract

Over the last few years there has been a notable increase in the extent and impact of network attacks. These attacks aim to compromise the confidentiality, integrity, or availability of data and network resources. Furthermore, decision-making becomes crucial in formulating proactive strategies on prevention or detection tasks in order to respond promptly to these network attacks. Besides, there are many approaches to identifying these attacks and making decisions but machine learning techniques are the most popular and reliable for identifying unknown attackers and achieving complete process automation. In this paper a set of Machine Learning methods is used, in particular boosting/bagging algorithms to enhance the attack detection process and to create multiple models and then combine them to produce improved results.

Keywords: Decision making; Artificial Intelligence; Machine Learning set; Networks Attacks; Boosting Models; Bagging models; Aggregation method.

1. Introduction

Network attacks refer to unauthorized actions or activities aimed at exploiting vulnerabilities in a computer network. These attacks can have various motives, including gaining unauthorized access to sensitive information, disrupting network operations, or causing damage to the targeted system. There are several types of network attacks: Denial or distributed of service (Bergamini et al., 2023; Batchu et al., 2022; Hasana et al., 2022), Malware attacks (Sheng et al., 2022; Rathorea et al., 2022), Phishing attacks (Krishnamurthy et al., 2008), Man in the middle attacks (Elrawy et al., 2023), Packet sniffing attacks (Hubballi et al., 2023), etc..

Several researchers proposed a variety of solutions for identifying and preventing network attacks. The authors of (Carlina et al., 2015) examine the cloud's open secure architecture advantages in brief, and focus on DDoS security threats in the cloud model along with the existing methods to defend against them with their pros and cons. According to (M. Tomassini et al.), achieving enhanced network resilience against targeted link attacks can be accomplished by leveraging easily accessible local information and employing a robustness measure that is both quick to compute and reliable. (Crespo-Martínez et al., 2023) Collected network flow data from SQL injection attack on the three most widely-used relational database engines and by using this dataset, various supervised learning-based models were trained with the mentioned datasets and the outcomes indicate the feasibility of detecting SQL injections attacks through NetFlow Version 5-based flow data. Another survey in network attacks (Genge et al., 2023) which focuses on an experimental evaluation of the impact of Denial or distributed of service (DDoS) attacks on communications in multiprotocol label switching (MPLS) networks.

The increase in network attacks poses a significant challenge to decision-making processes. Moreover, decision-makers must remain vigilant due to the intricate and dynamic nature of these threats. Staying informed

about emerging attack vectors, continuously evaluating the organization's network security stance, and making informed decisions are essential steps in strengthening defensive measures. (Elandaloussi et al., 2021) defines an approach for an IT infrastructure diagnostic in order to analyze, classify and take problems to closure in a short time face to a multi-criteria decision-making problem. (Jin et al., 2023) Propose an evolutionary game decision model for network attack defence based on regret minimization algorithm to optimize the learning mechanism through replication dynamic equations, and an optimal defence decision is formulated, aiming to significantly enhance the convergence and learning efficiency of defence decision algorithms.

Over the years, there have been continuous advancements in the field of cyber attacks and security, with the implementation of a diverse array of techniques aimed at safeguarding data. Today, Artificial Intelligence (AI) generates pertinent decisions and that one helps to perform analysis and further predictions (Kishore et al., 2023). Then, many researchers have demonstrated the importance of network attack prediction with different IA techniques. (Gadallah et al., 2024) propose an effective detection technique against DDoS attacks for both SDN data plane and control plane and using a parameter's value threshold to track the existence of the DDoS attack by tracking the average arrival bit rate for switch traffic with an unknown destination address in the data plane. (Wang et al., 2024) They utilize to determine whether the internet traffic is regular for detecting DDoS attacks using machine learning. In order to optimize the network's performance and deliver swift, efficient services to users, enhancements have been implemented by (Hua et al., 2019) incorporating artificial intelligence into the realm of network security marks a significant stride forward. By introducing a novel system detection algorithm rooted in the principals of AI, this endeavour has proven instrumental in bolstering the capabilities of AI for conducting rigorous security assessments on network systems. This innovative approach not only enhances the efficiency of security inspections but also sets the stage for a more robust and adaptive defence mechanism against evolving cyber threats. Furthermore, a single machine learning model can make prediction errors based on the accuracy of the training dataset but utilizing a set of technical algorithms can result in the development of a more robust and sophisticated detection technique when compared to alternative methods. (Dhanya et al., 2023) Aimed to evaluate the significance of various classical and set machine learning models in identifying intricate network attacks. This evaluation serves as a valuable guide for selecting robust strategies that can effectively navigate and counteract the challenges posed by advanced network attacks. Several studies (Amin et al., 2023; Otchere et al., 2022) show that set machine learning methods produce satisfactory results, though the evaluation rates may differ compared to other learning techniques. Our study is part of preventive network attacks to support decision makers with using set learning algorithms to achieve more accurate predictions. The main objective of our work is to reduce errors in predictive data analysis. Generally, using multiple machine learning algorithms separately can lead to prediction errors, which may vary depending on the type of algorithm and the accuracy of the training dataset. Indeed, our new algorithm combines all selected machine learning algorithms into one algorithm to achieve better results. The remainder of the paper is organized as follows: Section 2 is devoted to discussing a proposed approach by defining our algorithm named aggregation algo. The type and methodology used to collect datasets is explained in section 3. In section 4 we show and discuss the obtained results. Finally, the conclusions are presented in Section 6.

2. Proposed Approach

Set of methods are widely used in various domains, including machine learning competitions, finance, healthcare, and more, due to their ability to improve predictive performance, reduce over fitting, and enhance model robustness.

Boosting is an iterative set of methods where each model in the ensemble corrects the errors made by the previous ones. Popular algorithms include XGBoost (Sun et al., 2024) and Gradient Boosting Machines (Dombry et al., 2024), which sequentially fit new models to the residuals of the previous models.

Bagging is a powerful set learning technique used primarily in machine learning for improving the stability and accuracy of models.In our study, we introduce a novel algorithm designed to integrate multiple learning techniques into a unified framework. This algorithm incorporates the assignment of weights to each prediction iteration, enabling it to effectively predict all encountered attacks. By amalgamating various learning

methodologies. Our approach aims to streamline decision-making processes in handling diverse attack scenarios. Here are the different steps of our new algorithm:

Step1: Initially build the first model and execute a selected machine learning algorithms separately in order to obtain several predictions according to the same network attack dataset by using different algorithms.

Step2: Calculate error (residuals) for each algorithm.

Step3: Combines all weak learningin the new dataset as a new model (To generate a weak model).

Step4: Attribute new weight for each algorithm according to previous prediction (the highest weight for the algorithm that gave the best prediction).

Step5: Execute the same algorithms to this new model.

Step6: Aggregate results by taking account of thealgorithm's weights.

Step7: Add prediction from this model to the set model and obtain a final prediction.

3. Data set

Our dataset is a quantitative one. It contains benign and the most up-to-date common attacks, which resembles the true real-world data. It also includes the results of the network traffic analysis with labelled flows based on the timestamp, source, and destination IPs, source and destination ports, protocols and attack (CSV files).Furthermore, we dealing with a multi binary classification (0: Normal, 1: Attack).To address a predictive problem using different supervised learning algorithms, we typically adhere to three fundamental steps.

Collecting Representative Training Set

This involves gathering a dataset that accurately represents the problem we aim to solve. So, Ensuring the dataset's quality, diversity, and sufficiency is crucial for training robust models. Our dataset contains 125973 lines including 67343 as normal and 58630 as attack.

Selecting and Implementing Boosting/Bagging Algorithms

Boosting is a machine learning algorithms that combines multiple weak learners to create a strong learner. Algorithms like AdaBoost, Gradient Boosting, and XGBoost are popular choices due to their effectiveness in handling diverse datasets and improving predictive performance.

Training the Model

During training, the algorithm iteratively learns from the data, adjusting its parameters to minimize prediction errors and improve accuracy. This iterative process continues until the model achieves satisfactory performance or convergence.

4. Discussion & Result

This section describes the experimental results. The machine learning models and proposed models are implemented in python language. This work utilised XGBoost, Bagging, GradientBoost Machine learning approaches to predict the Network attacks and to validate our proposed aggregating algorithm. The metrics Accuracy, precision, recall and F1 measurewere employed to evaluate, revealing distinct patterns for the XGBoost, Bagging, GradientBoost and aggregating algo as depicted in the following Table1.

Table 1. Comparing network attacks prediction results.

Models	Accuracy	Precision	Recall	F1
XGBoost	95.17	94.51	92.19	91.05
Bagging	91.25	82.96	91.25	90.87
GradienBoost	95.06	94.43	91.94	90.65
Aggreg Algo	**99.84**	**98.67**	**97.95**	**97.83**

The dataset was divided into two subsets: one for training and the other for testing. Specifically, three quarters of the data were allocated for training purposes, while one quarter was reserved for testing the model's performance. The accuracy measures the proportion of all samples that are correctly classified by the model. It gives an overall assessment of the model's correctness. Recall is the ratio of correctly classified positive samples (attacks) to the total number of actual positive samples. It indicates the model's ability to capture all positive instances. Precision quantifies the proportion of correctly classified positive samples (attacks) among all samples that the model classified as positive. It reflects the model's accuracy in identifying true positive cases without misclassifying negatives. F1-Measure, also known as the F1-Score, represents the harmonic mean of precision and recall. It combines both precision and recall into a single metric, providing a balanced assessment of a classifier's performance.

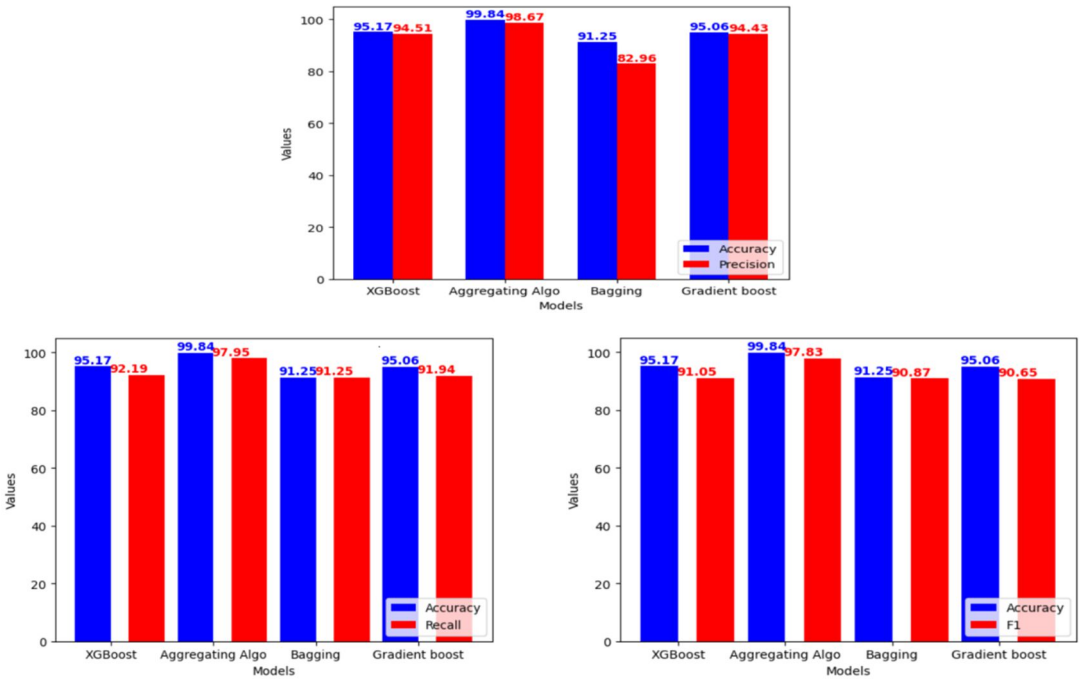

Figure 1: Models Metrics results.

The experimental results show that the proposed method efficiency by obtaining high precision, attacks detection rate compared to other related techniques as depicted in Figure1. Our approach gives a precision of 98,67% and Accuracy of 99,84%, while the best prediction of our implemented set machine learning model gives a precision of 94,51% and an accuracy of 95,17% with a precision deviation of 4,16%. As result, we observe that when combined, these diverse algorithms can provide more robust predictions than any single algorithm alone.

5. Conclusion

In this study, we were pointed out that set machine learning solutions offer a highly promising approach by effectively identifying potential unknown attackers and facilitating complete process automation. In addition, we developed a new model that combines a sequential and parallel set machine learning methods to benefit from both advantages, which has enabled us to achieve very promising results.

In this survey, the metrics used to evaluate the proposed system are Accuracy, Precision, Recall, F1-Measure and they give very promising values compared with another ML technique like XGBoost, Bagging, GradientBoost and can successfully accomplish classification, and prediction tasks in order to support technician for making a final decision about the attacks.

As future work, we plan to integrate unsupervised learning algorithms into our approach and provide further explanation on how our method calculates the weights assigned to these models. Additionally, we aim to elucidate how these weights can be incorporated within an unsupervised learning framework to enhance the effectiveness of our approach.

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Decision Support Systems Technology

Poster abstracts

24th International Conference on Group Decision and Negotiation &
10th International Conference on Decision Support System Technology
Human-Centric Decision and Negotiation Support for Societal Transitions

Research on resilience-oriented node important for combat system-of-system under emergency management

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Abstract

The effective implementation of pre-protection in emergency management is an important measure for complex systems to avoid or reduce losses in emergencies. Researching resilience-oriented nodes important for combat system-of-systems (CSoS) is an important link in promoting the practical application of strong resilient and intelligent CSoS under emergency management. This paper proposes a research framework on resilience-oriented nodes important for CSoS. Firstly, considering the impact of systems being protected on the CSoS, a resilience optimization model for CSoS based on capability curves is proposed; Secondly, two resilience-based node importance indexes, optimal protection time and resilience decrease value, were proposed. The former quantifies the priority that nodes should be protected, while the latter quantifies the loss of optimal resilience of the CSoS due to node protection delay; Then, considering the randomness of the impact of emergency events on equipment nodes in the CSoS, a ranking method for the importance of CSoS nodes based on Monte Carlo and Copeland scores was proposed; Finally, the effectiveness and superiority of the proposed framework were verified through numerical examples. The proposed index provides more practical guidance and decision-making for protection schedule planning and resource allocation than the classical centrality index. It has important theoretical support for the formulation of military emergency management decisions and the development and construction of resilient and intelligent CSoS in the military field.

Keywords: combat system-of-systems resilience; emergency management; node importance; node sorting; resilience optimization

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Human-Centric Decision and Negotiation Support for Societal Transitions

Command and Control Support Systems for military commanders: Achieving leadership superiority through AI

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Abstract

Due to the current developments in the security situation of the European Union, conventional warfare has once again become a significant part of the military threat spectrum. A key component to prevail on the battlefield in a conventional scenario is achieving leadership superiority over the opponent through better and faster decisions. Military commanders reach their decisions through various standardized Military Decision-Making Processes (MDMPs), which are embedded in complex Command and Control (C2) systems. Based on NATO's "Operations Process" (STANAG ATP-3.2.2) and the "Tactical Planning Process" (STANAG APP-28), the potential of AI applications for achieving leadership superiority shall be demonstrated.

The Operations Process represents NATO's C2 system and is a cyclic process that covers all activities that have to be undertaken during land operations on different echelons. At the highest level, the Operations Process consists of three different stages: Plan, Prepare, and Execute. Depending on the stage and activity, different applications of AI are possible, e.g., optimization of logistics or classification of objects on the battlefield based on image data provided by reconnaissance troops. One core element of the Operations process is the Tactical Planning Process, which represents the main MDMP. The Tactical Planning Process furnishes specific instructions for military decision-making and guides the commander towards their decision. One core result of the MDMP are different courses of action, which have to be assessed by the military commander. In this context, two outstanding applications of AI for military decision support are the generation and assessment of courses of action (COAs) and wargaming simulation, which are covered in recent papers (e.g., "COA-GPT: Generative Pretrained Transformers for Accelerated Course of Action Development in Military Operations" or "On games and simulators as a platform for the development of artificial intelligence for command and control" by Vinicius G. Goecks et al.).

The poster comprehensively depicts the various stages and activities encompassed within the Operations Process, along with its key stakeholders. Additionally, it explores potential applications of AI in this context. Through this exploration, the poster aims to shed light on the significance of AI in enhancing military decision-making processes and achieving leadership superiority on the battlefield.

Keywords: Artificial Intelligence; C2; Decision Support; MDMP; Leadership Superiority

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Human-Centric Decision and Negotiation Support for Societal Transitions

Accident prediction models as tool for road safety management

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Abstract

Road safety and accidents are global issues, resulting in thousands of deaths annually. Through the Vision Zero initiative, the European Commission promotes a road system that aims to prevent serious injuries or fatalities, emphasizing shared responsibility among road users, vehicle manufacturers, and authorities, focusing on safe system design, data-driven decision-making, and continuous improvement. In Portugal, strategic objectives for road safety are set in accordance with "Vision Zero 2030" by the National Authority for Road Safety (ASNR).

Accident prediction models are crucial resources for promoting traffic safety; providing support in defining targets and goals for road safety plans, identifying and managing hotspots, analyzing risk factors, and evaluating safety measures.

Ascendi is committed to the Vision Zero 2030 approach that is delineated in road safety plans. The company specializes in infrastructure asset management as well as operation and maintenance services. The use of a tool backed by actual data is essential for creating a reliable and workable road safety plan.

This study presents accident prediction models as a tool to support road safety plan to the Ascendi's six concessions, corresponding to a total of 627 km of extension and with data from 2016 to 2022. Generalized linear models were used, with Poisson and negative binomial distributions to fit data for two separate models – accidents with victims and total accidents. The road network was divided per concession and then, a segmentation process was defined to separate the network into homogeneous segments according to their geometric characteristics. Data from the infrastructure, traffic volume and road accidents are used, covering all Ascendi's network. After the segmentation process and the data treatment, the variables are evaluated and selected to be included in the models. At the end, various models are developed to better characterize the road network characteristics. To ensure the performance of the models, a validation process is used by splitting the data into two datasets one for calibration and the other for validation (also knowns as training and test). Various metrics to evaluate the performance are considered such as R^2, relative error, and CURE plot. After the validation of all models, a tool is designed to easily support the road safety management. The ultimate objective was to develop a user-friendly tool for practical implementation, thus contributing to accident prevention and providing a comprehensive framework for improving overall road safety.

Keywords: accident prediction model; road accidents; risk factors; road safety plan; decision making

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Preference Selection Dashboard for SMEs in Industry 5.0: Integrating Data from Varied Hierarchical Levels and Simulating Diverse Behaviours facing Uncertainty

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Abstract

Industry 5.0 is confronting challenges in both the efficient utilization of data and the effective collaboration with humans within companies. In this context, group decision making in Small and Medium Enterprises (SMEs), traditionally reliant on individual experiences and limited tools, must evolve to maintain competitiveness. Due to uncertainties, planning decisions (supply, production, distribution) often diverge from reality. Strategic, tactical, and operational (STO) levels are compartmentalized and do not consider constraints from other levels when selecting criteria for group decision making, even though actors at each level are affected. A group decision is made by using the same criteria for everyone. Thus, SME decision makers, including those from different hierarchical levels, may hold conflicting preferences on the same criteria. Group decision support systems are efficient solutions for facilitating co-decision making, but they typically rely on decision makers who must populate preference matrices based on their preferences for each criterion and alternative, often encountering a lack of knowledge. The construction of each matrix can be time-consuming, and there is not always good consistency between preferences for each actor.

Our objective is to propose a dashboard for each actor that consolidates all necessary information for weighing criteria during group decision making process, with the assistance of an existing decision support system. Each dashboard presents raw and processed data, along with Key Performance Indicators (KPIs) that incorporate constraints from other levels. In an example based on a real industrial problematic, we considered the choice of two policies: regular delivery or continuous delivery. Using our tool, actors can simulate various scenarios and behaviours in response to uncertainty using their respective dashboards, enabling them to select the preferred alternative based on different criteria. In our decision making situation, for example, actors at the strategic level will have access to financial data, customer satisfaction metrics, and Corporate Social Responsibility KPIs to assist them in selecting the best alternative based on each of those criteria. The data gathered in these dashboards can vary in type, and the associated uncertainty may exhibit different dispersion or models based on their origin and their impact: probabilistic when derived from historical data, fuzzy subsets when based on experiences, etc. Additionally, for each actor, these data can be aggregated differently to prioritize the most relevant information. The combination of the dashboard and the group decision support system use would facilitate the convergence of the group decision process.

Keywords: Industry 5.0; Small and Medium Enterprises; Production planning; Uncertainty; Multi actors, multi criteria decision making.

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