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UNIVERSIDADE DO PORTO

IEMS '25

16TH INDUSTRIAL ENGINEERING AND MANAGEMENT SYMPOSIUM

In-Person event
JANUARY 7th, 2025

Colégio Luso Francês
Rua do Amial 442, 4200-055 Porto

https://fe.up.pt/degi/iems25/

Abstracts Booklet of IEMS'25

16th Industrial Engineering and Management Symposium:

The Impact of DEGI Research on Society

Editor: José Fernando Oliveira

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Porto, January 7th, 2025

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Organizing Committee:

Catarina Santos, Francisco Maia, João Antunes, Marcella Mendes, Mariana Casalta, Nuno Marques, Sandra Monteiro, Sérgio Castro, Tiago Monteiro

Acknowledgment of Reviewers:

Extended abstracts have been reviewed in draft form by individuals with diverse perspectives and technical expertise. The purpose of this independent review was to provide critical comments to assist the authors in making their published abstracts and their presentations as sound as possible. We wish to thank the following individuals for their reviews:

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Additionally, we would like to acknowledge the authors that submitted to IEMS'25:

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Although the reviewers provided many constructive comments and suggestions, they did not see the final draft of the extended abstracts before their release. Responsibility for the final content of the abstracts rests entirely with the respective authors.

Organised by:

DEGI – Department of Industrial Engineering and Management

Faculty of Engineering, University of Porto

Porto, January 7th, 2025

Welcome!

Dear IEMS'25 Participants,

Welcome to the 16th Industrial Engineering and Management Symposium (IEMS'25), proudly hosted by the Department of Industrial Engineering and Management (DEGI) of the Faculty of Engineering of the University of Porto (FEUP). Since 2010, this event has brought together students, researchers and industry professionals to exchange ideas, build relationships and explore new solutions to today's challenges.

This year's programme offers an exciting and diverse programme that reflects our commitment to fostering innovation and collaboration. The day will begin with presentations from our talented PhD students, who will share their research on topics such as online grocery optimisation, inventory management and capacity planning. These projects highlight the breadth and relevance of industrial engineering and management in tackling real-world problems.

We are also delighted to be hosting two roundtables. The morning session, moderated by Marta Campos Ferreira, will focus on "Shaping the Future of Mobility". With distinguished speakers Ana Paula Vitorino, José Gomes Mendes and Paulo Humanes, this discussion will explore governance, innovation and the integration of transport systems in sustainable mobility. In the afternoon, we will connect with alumni of our PhD programmes, offering valuable perspectives on career paths and professional development.

The symposium will also feature engaging pitches and presentations from 19 PhD students, giving them the opportunity to present their ideas and receive feedback from a diverse audience. These dynamic sessions will be complemented by networking breaks where attendees can network, share experiences and explore potential collaborations.

I would like to take this moment to thank the dedicated organising committee, made up of our exceptional PhD students: Catarina Santos, Francisco Maia, João Antunes, Marcella Mendes, Mariana Casalta, Nuno Marques, Sandra Monteiro, Sérgio Castro and Tiago Monteiro. Their hard work, creativity and passion were the driving force behind the success of this symposium. Their diverse research interests and commitment to excellence truly embody the spirit and values of DEGI and its ecosystem. This event would not have been possible without their dedication and teamwork.

I would also like to thank all the speakers, students and contributors who make IEMS'25 possible. Your dedication to the advancement of our field is what makes this event so special. I encourage everyone to make the most of this opportunity to learn, network and be inspired.

Thank you for being part of IEMS'25. Let's make this a memorable and meaningful event for all.

Best regards,
José Fernando Oliveira
Head of the Department of Industrial Engineering and Management
Faculty of Engineering, University of Porto

Porto, January 7$^{\underline{\text{th}}}$, 2025

Information for Participants

The symposium will take place at Colégio Luso-Francês, in the Francisco de Assis Auditorium. The venue information is detailed below:

- Pedestrian Access – Rua Cel. Almeida Valente 599, 4200-061 Porto
- Parking Access – Rua Cel. Almeida Valente 495, 4200-031 Porto

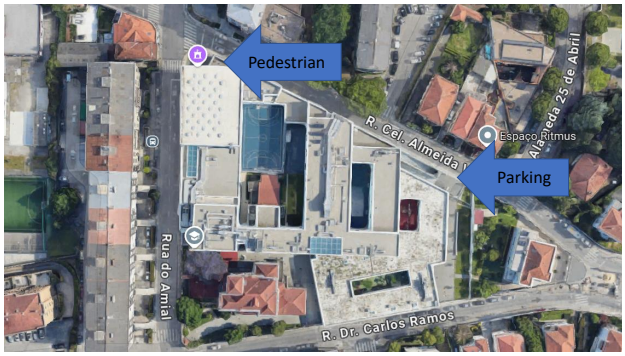

Figure 1: *Accesses.*

Figure 2: *Auditorium.*

A map with the location of the different entrances of the venue is depicted in Figure 1. There is a garage with 100 parking spaces available for participants. For those relying on public transport, several bus lines are available in the area (lines 300, 301, 600, 704). The nearest metro stations, Polo Universitário and IPO, are within a 15 minute walk.

The reception of participants will be in the foyer next to the auditorium, immediately after the pedestrian access. The access from the garage to the foyer is near the pedestrian access. The auditorium where the presentations will occur is depicted in Figure 2. There is Wi-Fi access in the building (Password: audit.2021).

Guidelines for Speakers

- The room is equipped with a video projector and laptop computer.
- Arrive at your session at least 10 minutes before it begins.
- Send your presentation to iemssubmissions@fe.up.pt until the day before IEMS '25 begins.
- Time your presentation to fit in the allotted time:

  PhD Projects: 15 minutes plus 5 minutes for Questions and Answers.

  Elevator Pitches: allotted time of 3 minutes, with Questions and Answers held together at the end of the session.
- Presentation certificates will be available at the end of the symposium.

Guidelines for Voting for the Best Elevator Pitch Award:

During the event, PowerPoint slides containing the general idea of each research project (known as elevator pitches) are presented. The elevator pitches are also available in this Book of Abstracts, at the beginning of each extended abstract, and the IEMS'25 website: `https://fe.up.pt/degi/iems25/` .

During the event, each participant can vote online to **three elevator pitches** by visiting the IEMS'25 website, and the elevator pitch with maximum votes is awarded.

Porto, January 7th, 2025

Program Schedule

Tuesday, January 7th

Reception of the Participants: 9:00 – 9:20 (*Foyer*)

Opening Session: 9:20 – 9:30 (*Auditorium*)

Morning Chair: Flávia Barbosa

PhD Projects: 09:30 – 10:30 (*Auditorium*)

A.1 Optimizing Online Grocery Service: from Customer Understanding to Multichannel Profitability. Daniela Fernandes, Fábio Neves-Moreira, Jan C. Fransoo, Pedro Amorim

A.2 Fair Order Fulfillment in Online Marketplaces via Reinforcement Learning. Sérgio Castro, Willem Jaarsveld, Gonçalo Figueira, Bernardo Almada-Lobo

A.3 Sequential decision making in the inventory management of Port wine. Miguel Lunet, Fábio Neves-Moreira, Marjolein Buisman, Pedro Amorim

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Coffee-Break: 10:30 – 11:00 (*Foyer*)

Round Table: 11:00 – 12:00 (*Auditorium*)

B.1 Shaping the Future of Mobility: Governance, Innovation, and Interdisciplinary Approaches. Ana Paula Vitorino (AMT, Former Portuguese Minister of the Sea), José Gomes Mendes (U. Minho, Former Secretary of State for Mobility, Environment and Planning) and Paulo Humanes (LOGIT). Moderator: Marta Campos Ferreira (DEGI)

Break: 12:00 – 12:10 (*Auditorium*)

Elevator Pitches: 12:10 – 13:15 (*Auditorium*)

Felipe Yamada, Francisco Maia, João Antunes, Jongmin Han, Luciana Yamada, Marcella Mendes, Mariana Casalta, Nuno Marques, Radner Petrucha, Raziyeh Ghanbarifard, Sandra Monteiro, Sayeh Mahani, Tiago Monteiro

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Lunch: 13:15 – 14:30 (*Foyer*)

Porto, January 7th, 2025

Afternoon Chair: Gabriela Beirão

Round Table: 14:30 – 15:45 (*Auditorium*)

C.1 Beyond the Thesis: The Lasting Impact of a PhD Journey on Professional Success. Luiz Henrique Cherri (Newfoundland Capital Management, former ODM Consulting), Cristiane Ferreira (Amazon), António Almeida (INESC TEC, former Farfetch) and Pierre Polzin (Portuguese Health Regulatory Authority). Moderator: Bernardo Almada-Lobo (DEGI)

Coffee-Break: 15:45 – 16:15 (*Foyer*)

PhD Projects: 16:15 – 17:15 (*Auditorium*)

D.1 Aligning Education Systems' achievements with strategic goals for European countries. Fernando Osório, Flávia Barbosa, Ana S. Camanho

D.2 Incorporating substitution effects in demand forecasting for perishable products. Mariana Sousa, Sara Martins, Maria João Santos, Pedro Amorim

D.3 Glass packaging capacity planning. Gustavo Resende, Luis Guimarães, Bernardo Almada-Lobo

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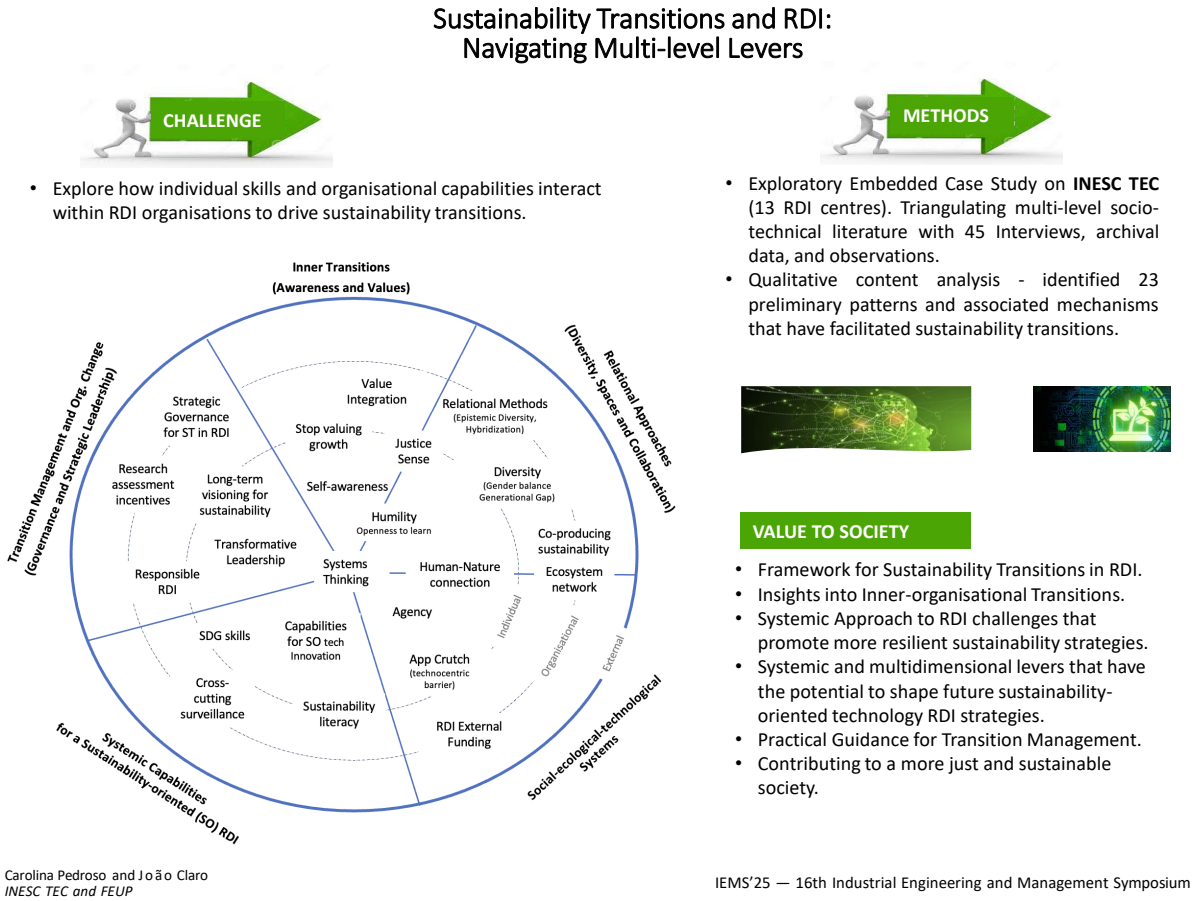
Award for the best elevator pitch and Closing Session: 17:15 – 17:30 (*Auditorium*)

Abstracts

Sustainability Transitions and RDI: Navigating Multi-level Levers

Carolina Pedroso*, João Claro*

* *INESC TEC and Faculdade de Engenharia, Universidade do Porto*



1 The Challenge

A transformation toward sustainability has increasingly been argued for as a vision of the future for society. The United Nations Agenda for Sustainable Development has significantly prioritised Research, Development, and Innovation (RDI), which actively contributes to Sustainability Transitions (ST). This momentum invites researchers and innovators to understand better human-nature interactions, exploring human, environmental, social, and economic pillars of sustainability and transforming that knowledge into more sustainable development paths.

Different RDI strategies and capabilities at multiple levels, reframing how science and society relate to each other and how ST knowledge is produced and applied, are essential in this process (Baker-Shelley et al., 2017). In this context, this research entails answering the following question: How do individual skills and organisational capabilities emerge and interact to enable progress in transitions toward sustainability in RDI organisations?

2 The Methodology

We adopted an exploratory design to address this challenge, reflecting the early stages of sustainability transition literature about systemic levers, particularly in the RDI context. Our conceptual framework draws upon the Multi-Level Perspective (MLP), a socio-technical model that examines how skills and capabilities at different levels interact to drive sustainability transitions. We applied an embedded case study methodology, centring on INESC TEC, a large-scale research organisation with 13 embedded RDI centres, each featuring diverse areas of science, technology and innovation, as well as distinct methodological approaches and perspectives. Our data collection encompassed archival research, 45 interviews, direct observations, and qualitative content analysis to identify patterns and mechanisms that have facilitated sustainability transitions within the organisation over the past decade.

Although sustainability science has made notable progress, much of the focus has been on external phenomena such as ecosystems, governance, and economic systems, often overlooking the critical role of internal, individual-level transformations connections to organisational transitions. Therefore, our analysis also considered "inner transitions" — shifts in individual values and awareness that directly contribute to sustainability transitions in RDI practices. Through triangulation of systemic literature and our case study data, we have initially identified 23 key patterns (Figure 1) that align in some layers with established sustainability literature while highlighting under-explored internal levers, such as self-awareness, justice sense, relational approaches and specific values such as humility.

3 The Value to Society

RDI organizations are ideal sites for visioning, neutral convening, facilitating participatory processes and ecological and social dialogue. They are also places for innovation and experimentation. This research offers a more holistic view of the transition process by empirically observing the "inner-organizational transition" emergence of levers organized in five dimensions: Inner Transitions, Relational Approaches, Social-ecological-technological Systems, Systemic Capabilities for a Sustainability-oriented RDI, and Transition Management. The exploratory insights about ST levers elaborated in this set of dimensions offer a systemic, broad, and diversified perspective of the complex process of transitioning an RDI. Specific insights in each dimension are explored as follows.

In the first dimension, Individuals' inner transitions, levers related to values, beliefs, and self-awareness were crucial for driving the broader societal transitions necessary for sustainability. On the second dimension, our results encompass the discussion over "relational approaches" in ST, which highlights the need to rethink how RDI strategies and practices are developed. Relational approaches emerged in our case and emphasised the importance of integrating diverse perspectives and epistemologies, including ancestral knowledge and multidimensional diversity, highlighting the ethical responsibilities arising from human-environment relationships. This approach aligns with broader calls to hybridize knowledge production in sustainability RDI, ensuring that multiple ways of knowing, being and acting are incorporated into sustainability transitions. This perspective contributes to sustainability RDI efforts addressing issues of marginalisation and power imbalances in the co-production of knowledge.

Associated with these relational and justice values, another dimension discussed in our work results, the "Social-Ecological-Technological Systems" (SETS), advances a more integrated approach to RDI strategies for addressing global challenges like climate change. Traditional techno-centric solutions may result in unexpected trade-offs, neglecting the broader ecological and social dimensions critical to long-term sustainability. These results suggest moving beyond these limitations by incorporating ecosystem services and nature-based solutions visions into technology RDI strategies, thereby creating more holistic and resilient responses to sustainability challenges.

Several specific capabilities, such as cross-cutting surveillance, systems thinking, sustainability literacy and SDG skills, were also identified as potential levers on the dimension of Systemic Capabilities for a Sustainability-oriented RDI. Finally, our work also underscores RDI organisational-specific levers that rethink transition management strategies, contributing to more sustainable and equitable technological plans and pathways inside RDI organisations.

Sustainability transitions in and from RDI involve changing configurations, capabilities and visions from a linear to a systemic and much more complex view of RDI organisations. New methods, visions, skills, and capabilities are desirable for mutually identifying opportunities and planning practical sustainability innovations and organisational changes. Identifying and framing the patterns of levers contributing to ST enhances our understanding about change processes for sustainability and the potential of RDI-led path generation. Our research offers multifaceted context-sensitive levers, dimensions and inter-connected nested spaces for sustainability transformations in RDI complex systems. By embracing the potential presented in inner transitions, epistemic diversity and power dynamics, fostering collaborative knowledge production and dynamic capabilities and acknowledging sustainability governance's nested and multiscale nature transitions, these results provide a more inclusive and equitable framework for addressing the complex and interconnected challenges of sustainability transitions in RDI. In conclusion, this research contributes to the literature on sustainability transitions by highlighting the role of specific, systemic and multidimensional levers that have the potential to shape future sustainability-oriented technology RDI strategies, contributing to a more just and sustainable society.

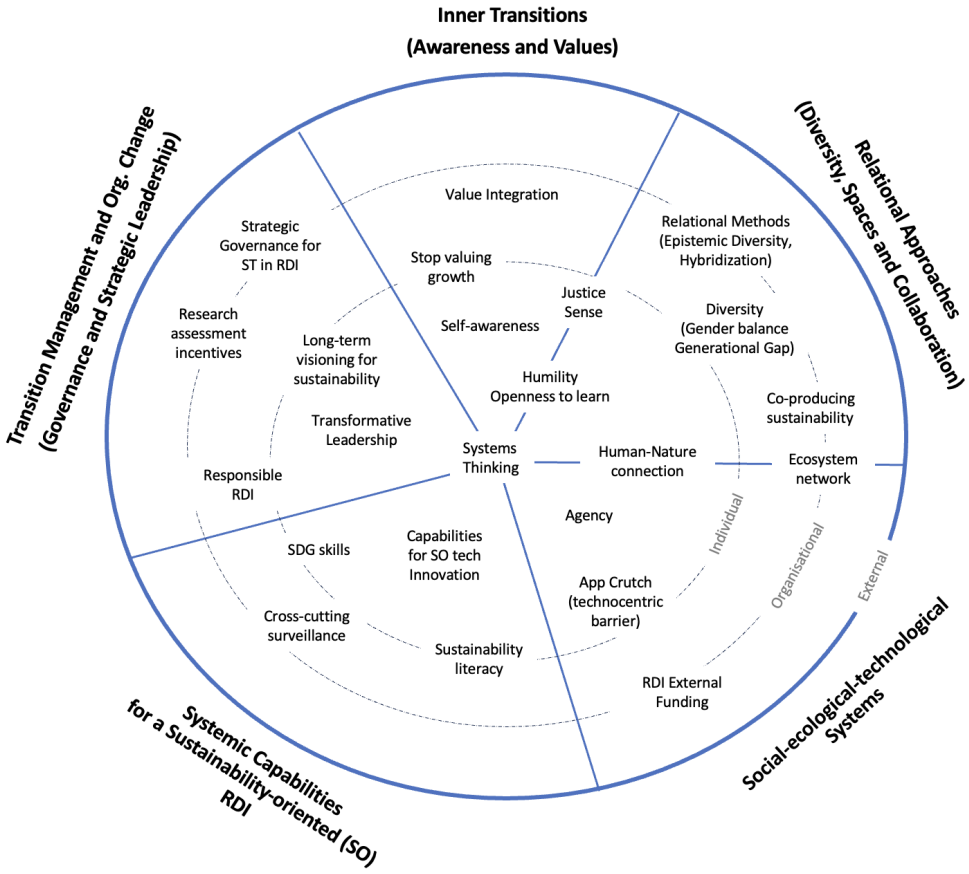


Figure 1: Systemic Levers of Individual-organizational-external Continuum of Sustainability Transitions (ST) on a Tech RDI Embedded Case. The image summarises these levers and their relation with the different literature dimensions of ST holistically. Own Design, inspired by Baker-Shelley et al. (2017) A conceptual synthesis of organisational transformation: How to diagnose, and navigate, pathways for Sustainability at universities? Journal of Cleaner Production, 145.

Optimizing Online Grocery Service: from Customer Understanding to Multichannel Profitability

Daniela Fernandes[a], Fábio Neves-Moreira[a], Jan C. Fransoo[b], Pedro Amorim[a]

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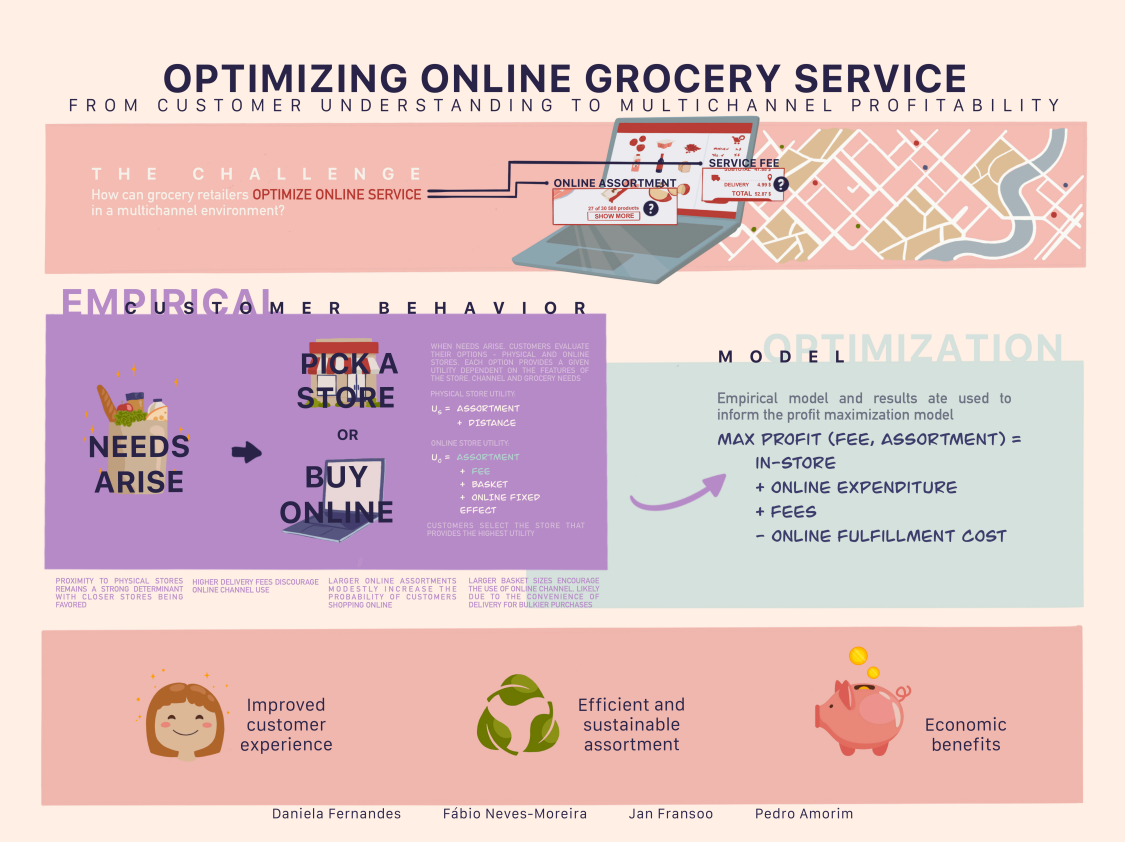
[b]*School of Economics and Management, Tilburg University, 5037 AB Tilburg, Netherlands*



1 The Challenge

The grocery retail sector increasingly relies on multichannel strategies, integrating online services with traditional physical stores to reach a broader customer base and meet diverse shopping preferences. Although online orders offer convenience and flexibility, they bring high operational costs, particularly in terms of labor, equipment, and delivery expenses, which often exceed what customers are willing to pay in fees. Meanwhile, physical stores continue to attract customers by providing immediate product access without additional fees. As a result, customers often rely on both channels, choosing between them based on factors like convenience, assortment availability, delivery fees, and grocery needs. This multichannel behavior poses a complex challenge for grocery retailers making planning decisions, who must not only anticipate the impact of the provided service on demand, but also consider the channel demand inter-dependencies.

In this study, we address a key challenge faced by grocery retailers: determining the optimal online grocery

service that balances online assortment and delivery fees with customer preferences and profitability goals. In a multichannel environment, this requires a strategy that considers the impact of online service decisions on a retailer's physical store demand as well. Existing research has generally examined online and offline channels in isolation, often overlooking how delivery fees, store proximity, and assortment interact to influence customer choice and expenditure across channels. Furthermore, studies on channel demand substitution and complementarity typically quantify these effects directly, without investigating the underlying customer needs and channel-specific capabilities that drive them. Our study fills these gaps by analyzing how delivery fees, assortment size, and store proximity influence customer behavior in a multichannel grocery context. Our objective is to develop strategies that optimize online service to enhance profitability across channels, specifically by determining the fee and online assortment.

2 The Methodology

This study combines empirical analysis of customer behavior with an optimization model to create actionable strategies for online grocery services in a multichannel environment. We begin with an empirical analysis of transactional data from a partner retailer, employing a Multinomial Logit (MNL) model to examine customer store choice behavior across online and offline channels. The MNL model quantifies how factors such as store distance, assortment size, delivery fees, and grocery needs influence customer preferences and spending patterns. By examining both store-related factors (e.g., proximity, assortment size, fees) and variable factors related to grocery needs, this analysis provides a nuanced understanding of customer demand dynamics within the grocery sector.

The results from the empirical analysis serve as inputs for our optimization model, which seeks to maximize profitability by adjusting online service variables, specifically, delivery fees and online assortment size. Using a continuous function framework, we model how changes in online assortment and delivery fees affect demand and profitability across both channels. The model includes real-world cost constraints for online orders. Additionally, we also explore potential scale economy effects and the effect of assortment on fulfillment cost.

While we derive analytical conclusions from the problem structure, the optimal solution cannot be obtained in closed form, prompting us to rely on numerical analysis. We evaluate the behavior and robustness of the optimization model under varying market conditions, fulfillment costs, and customer behavior scenarios. By testing different sensitivities to delivery fees, assortment preferences, and store proximity, as well as operational cost structures and market characteristics, we translate the model results into actionable managerial insights.

3 The value to Society

The insights from this study offer value to both retail practitioners and society at large. For grocery retailers, this research provides actionable strategies for managing and optimizing multichannel operations, an area of growing importance as customers increasingly demand seamless online and offline shopping experiences. By tailoring delivery fees and optimizing assortment sizes, retailers can enhance customer satisfaction by offering more relevant product selections and streamlined service across channels.

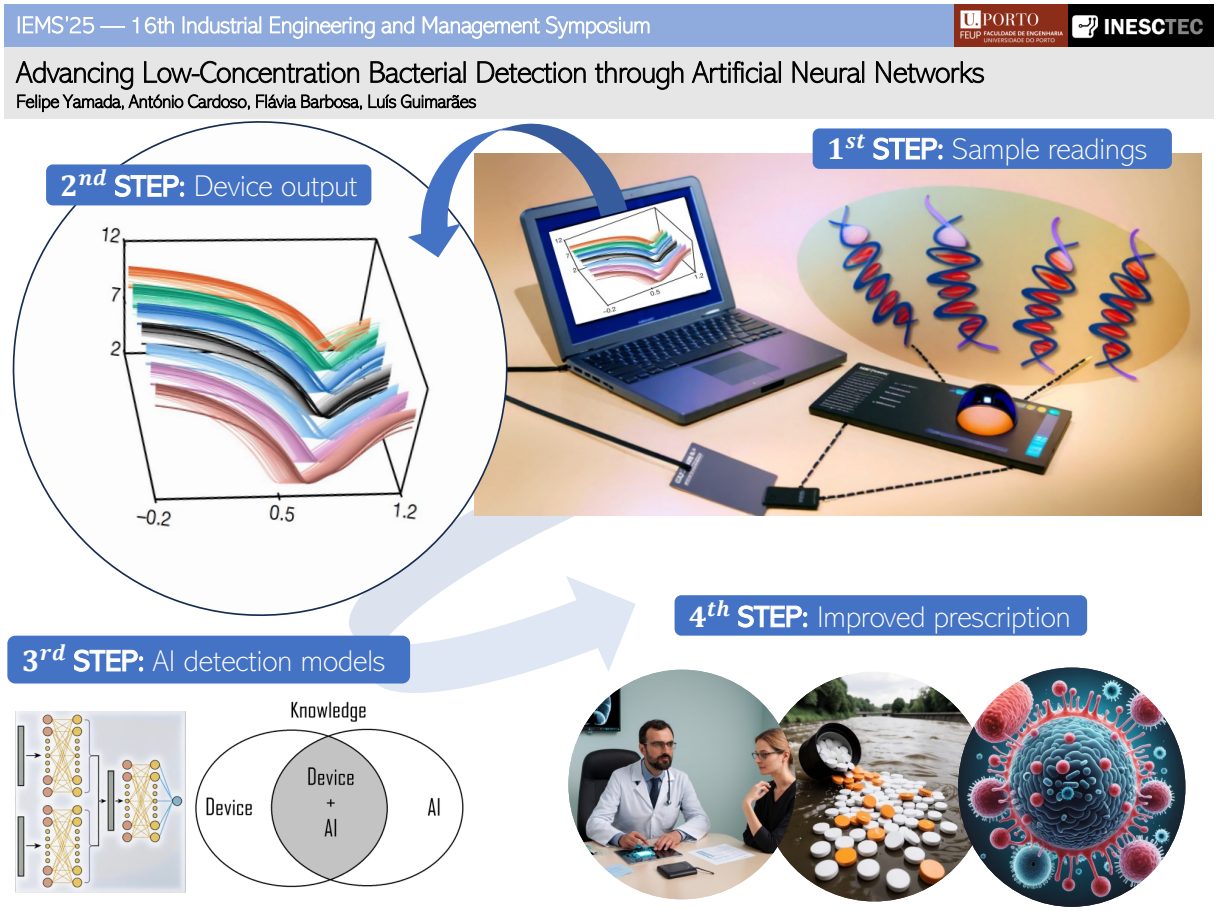
From a sustainability perspective, the study's insights into efficient assortment and fees can contribute to more responsible resource use. For example, by optimizing the online assortment size to better match local demand patterns, retailers can minimize excess inventory and reduce the likelihood of food wastage. Additionally, by limiting the number of products offered online, retailers can streamline logistics and reduce transportation costs, thereby lowering the overall environmental impact of grocery operations.

For society, this study supports greater accessibility in grocery shopping by exploring fee and assortment strategies that sustain the economic viability of home delivery services, benefiting customers with limited mobility or those in areas with fewer store options. Ultimately, by enhancing grocery retail profitability through optimized delivery fees and efficient assortments, this research helps ensure that retailers can continue offering cost-effective, reliable services across digital and physical channels, meeting diverse customer needs while supporting economic and environmental sustainability.

Advancing Low-Concentration Bacterial Detection through Artificial Neural Networks

Felipe Yamada * §, António Cardoso §, Flávia Barbosa * §,Luís Guimarães * §

* *Faculty of Engineering, University of Porto*
§ *INESC TEC*



1 The Challenge

Antimicrobial resistance (AMR) presents a significant global challenge, contributing to nearly 5 million deaths each year due to drug-resistant infections. In the European Union alone, AMR is responsible for over 33,000 fatalities annually, which results in approximately 1.5 billion euros in healthcare costs and productivity losses. The World Health Organization (WHO) has identified AMR as one of the top ten public health threats, encouraging countries to implement action plans to address antibiotic misuse. If left unaddressed, WHO forecasts that AMR could lead to 10 million deaths per year by 2050, surpassing mortality rates from diseases such as diabetes, heart disease, and cancer. To effectively combat AMR, a comprehensive strategy is crucial. This strategy should include the development of AI-driven miniaturized point-of-care devices that can identify AMR pathogens, resistance genes, and antibiotic residues across human and animal health, food, and environmental contexts. Such innovative approaches

would help establish a detection network, enabling timely preventive measures, reducing antibiotic misuse, and ultimately lowering the risk of future pandemics.

2 The Methodology

This study aims to improve the accuracy of bacteria and antibiotic identification across varied conditions by leveraging data analysis and artificial intelligence. The research explores two main approaches. The first approach employs a graphene device, while the second utilizes an artificial nose that senses volatile organic compounds (VOCs).

The first approach utilizes a microfluidic lab-on-a-chip device for sample readings. This device combines molecular recognition techniques with graphene-based sensors to facilitate sensitive detection. Specifically, it incorporates bio-recognition molecules, such as DNA and bacteriophage proteins, which selectively bind to target bacteria. These interactions generate distinct electrical signals that reflect the molecular composition of the sample upon binding. The device comprises 20 graphene sensors, each producing a unique real-time response curve. These curves vary according to bacterial concentration, environmental conditions, and the fabrication characteristics of the sensors. The research monitors the evolution of the response curves over consecutive readings to determine whether shifts in the curves can indicate bacterial concentration, particularly at low levels. An Artificial Neural Network (ANN) regression model serves for data interpretation. This model takes two inputs - a baseline reference curve and an unknown sample curve - and outputs the inferred concentration difference between the two. This approach enhances the sensitivity and accuracy of bacterial quantification, especially for samples at low concentrations.

In the second approach, the artificial nose detects and differentiates bacterial species by analyzing VOCs emitted from cultivated bacterial samples. This device integrates four distinct ionizing lamps operating within a specific ionization range to generate electrical responses corresponding to each sample's VOC profile. These responses reveal unique VOC patterns for each bacterial species, allowing for capturing subtle differences in VOC composition. Analysts classify bacterial species by examining these distinctive patterns based on their specific VOC emissions. To address the limited dataset, the study employs a pre-trained image recognition model for feature extraction. The electrical outputs from the artificial nose are processed and converted into image representations that reflect the unique VOC signatures of each bacterial sample. For classification, these images are compared to a library of reference images corresponding to different bacterial classes, using image-based pattern recognition to accurately identify bacterial species. This approach compensates for the limited data and enhances classification accuracy by translating complex VOC data into visual patterns.

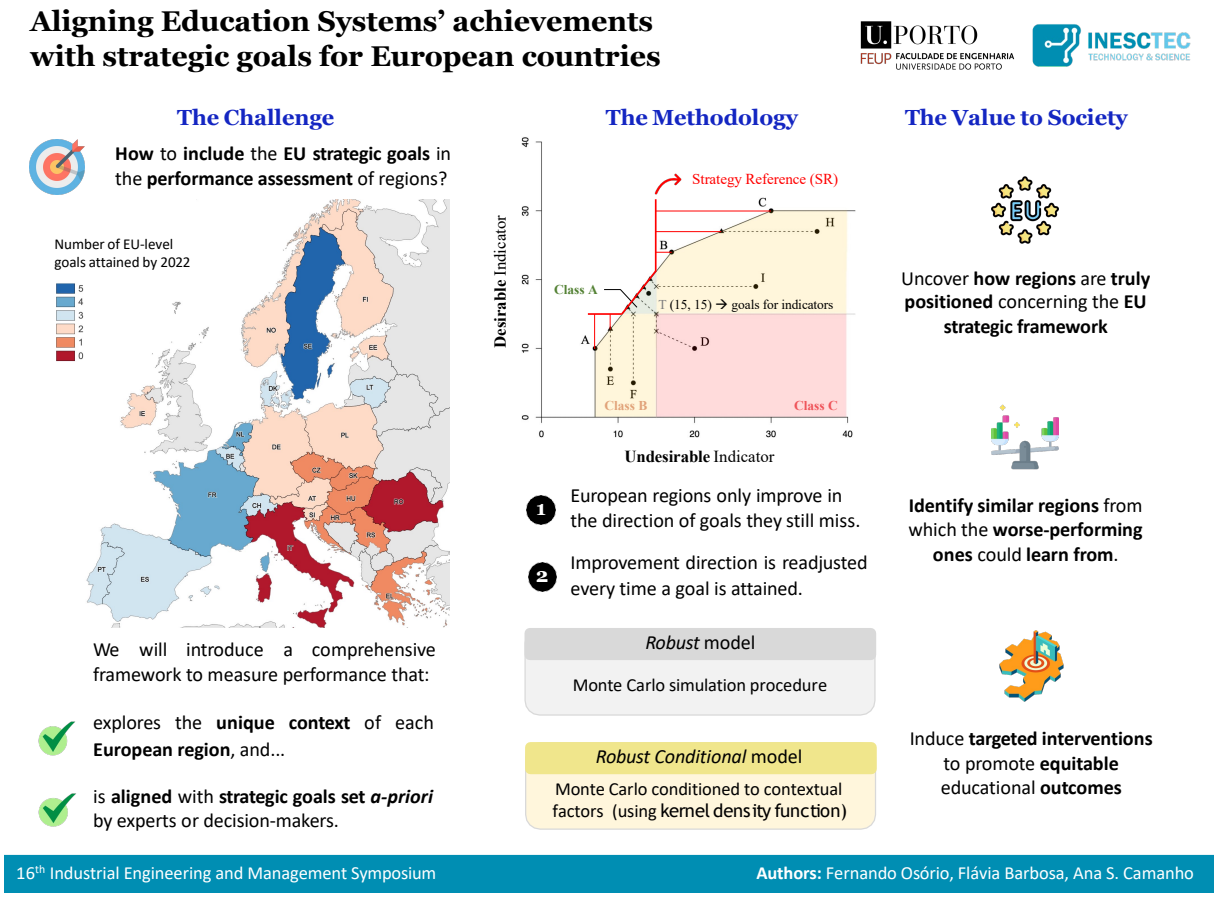
3 The value to Society

Advancements in this field hold the potential to significantly enhance human and animal health, promote environmental sustainability, and improve food safety. One urgent challenge is the rise of drug-resistant bacteria, which threatens healthcare systems, resulting in resource strain and costly treatment options. The economic impacts of antibiotic resistance extend beyond healthcare costs; they can lead to decreased productivity due to prolonged illness, increased hospital stays, and a more significant burden on healthcare resources. Additionally, industries such as agriculture may face challenges related to livestock health, affecting food supply and market stability. A primary factor contributing to the emergence of these resistant strains is the overprescription of antibiotics, complicating treatment decisions, and increasing health risks. Rapid diagnostic tests can empower healthcare providers to prescribe antibiotics more accurately and promptly, reducing the likelihood of misuse and overprescription. This proactive strategy is essential in effectively combating antibiotic resistance and mitigating its economic effects.

Aligning Education Systems' achievements with strategic goals for European countries

Fernando Osório *, Flávia Barbosa *, Ana S. Camanho *

* *INESC TEC, Faculty of Engineering, University of Porto*



1 The Challenge

The efficient provision of public services is one of the milestones that guarantees the well-being of nations in the long run. Thus, assessing the efficiency of public services is at the top of the agenda of governments to ensure the competitiveness, prosperity, and social cohesion of countries. Education is a critical sector whose performance is monitored adopting different perspectives, giving rise to academic studies published in the literature. Education Systems are required to provide high-quality educational services while minimizing the amount of public money devoted to them, given the need to control budgets.

Several countries are currently participating in international large-scale assessments, such as the Programme for International Student Assessment (PISA), the Trends in International Mathematics and Science Study (TIMSS), or the Progress in International Reading Literacy Study (PIRLS), to monitor educational outcomes in basic and secondary education. Nevertheless, assessing achievements at other stages of education, considering the heterogeneity of contextual conditions, the resources available and the country-specific regulatory frameworks remains under-explored.

Although European Union (EU) countries are responsible for their Education Systems, the EU monitors their performance according to the strategic framework 'Education and Training 2030' (ET2030), which sets out five common objectives: (i) improving quality, equity, inclusion and success for all in education and training; (ii) making lifelong learning and mobility a reality for all; (iii) enhancing competences and motivation in the education profession; (iv) reinforcing European higher education; (v) supporting the green and digital transitions in and through education and training. To achieve these objectives, seven benchmarks and their respective EU-level goals were established for Europe to achieve cohesion.

The alignment of national policies with the strategic framework for European cooperation in Education and Training helps each Member State to make good use of their available resources, typically limited, to maximise the educational outcomes ranging from early childhood education to lifelong learning. Most cross-country studies focusing on educational performance rely on frontier techniques, in particular Data Envelopment Analysis (DEA), to measure the efficient conversion of resources into educational outcomes. These methods provide an overall picture of how well countries perform when evaluated against an empirical 'best practice' frontier defined by their most efficient peers. In the particular context of the Strategic Framework for Education and Training, the performance of European countries is monitored in terms of their educational outcomes without considering resource constraints, relying on the DEA technique under a Benefit-of-the-Doubt (BoD) approach.

The literature on measuring educational performance including strategic goals is very limited, and the existing studies focusing on the EU strategy for Education and Training do not address the existing gap between benchmarking target levels (that countries are proposed to attain to reach the empirical frontier when evaluated using frontier techniques) and more ambitious EU-level goals. This research intends to introduce a comprehensive BoD framework for performance measurement aligned with strategic goals set *a-priori* by experts or decision-makers, and validate it with the empirical assessment of European Education Systems using the most recent data available on the ET2030 benchmarks, and their respective EU-level goals as reference levels.

2 The Methodology

First, we review the most frequently employed methods for measuring performance in the education sector, followed by a comprehensive overview of studies on cross-country comparisons, with a particular focus on the educational stage assessed, the data source, and the method employed. In addition, three studies concerning the Strategic Framework for Education and Training are discussed in detail, as they provide the latest evidence on the topic of this research.

Then, we propose an iterative process based on an innovative directional BoD model to assess the performance of the Education Systems of 27 European countries. The framework we propose allows for setting benchmarking targets at the 'best practice' frontier aligned with strategic goals specified *a-priori* by experts or decision markers, which in the context of this research correspond to the ET2030 goals. The main novelty we introduce is that the improvement direction specified for each country may be readjusted (at each iteration) several times to ensure that the targets values obtained at the 'best practice' frontier do not exceed the strategic goals associated with the indicatros being improved. The purpose of the iterative process we propose is to find the most balanced and closest position possible to the strategic goals (without exceeding them) given the observed evidence limited by the 'best practice' frontier.

Additionally, besides the measurement of technical performance against the 'best practice' frontier, we propose the estimation of composite indicator scores denoting the overall performance of European countries against a 'strategy' reference, which extends beyond the 'best practice' frontier and considers the real distance between countries and the EU-level goals.

Finally, we conclude with a qualitative recommendation for the revision of some EU-level goals, namely on early school leaving, early childhood education and care, and tertiary education attainment, as most European countries have already reached or are close to reaching the level envisaged for 2030. Low achieving in basic skills is identified as a critical area and a priority of intervention across most countries.

In the second part of the research we start by providing an extensive review of the studies conducted at regional level, with a particular focus on those that examine the evolution of performance over time,

test the reliability of the models, or include any contextual factors, which will be critically discussed and included in the performance evaluation, if considered to have a relevant impact on educational outcomes.

Then, we employ a robust conditional approach based on a novel directional BoD model to evaluate the performance of the Education Systems of more than 100 European regions. This approach also incorporates the 2030 strategic goals for Education and Training while defining *a-priori* the direction for improvement that each European region should follow. The robust version of the model is obtained following a Monte Carlo simulation procedure to address the deterministic nature of BoD by making the model less susceptible to atypical observations, such as European regions performing exceptionally well that may shift the position of the empirical frontier upwards and significantly impact the evaluation and distort the results. On the other hand, the conditional version of the robust BoD estimator will address the heterogeneity among European regions subject to different regulatory contexts. Contextual variables are included to condition the Monte Carlo procedure to a higher probability (based on an estimated kernel density function) of drawing European regions with more similar contexts to the region under analysis.

Finally, the evolution of educational performance across the different European regions over time is explored by applying a Global Malmquist Index (GMI), and the assessment of convergence is covered with the estimation of σ-convergence and β-convergence. While the first assesses whether the dispersion of the performance of European regions decreases over time, the second evaluates whether lower-performing regions tend to improve faster than the higher-performing ones.

3 The value to Society

This research introduces a comprehensive BoD framework that not only accounts for the unique context of each European Education System through a robust conditional approach, but also incorporates the 2030 strategic goals for Education and Training in the performance assessment. By doing so, we will be able to uncover how European Education Systems are truly positioned concerning the EU strategic framework for Education and Training.

Additionally, including contextual factors that have a relevant impact on educational outcomes may help to identify more tailored and appropriated European regions from which the worse-performing ones could learn best practices, further enhancing the potential for knowledge exchange and improvement across regions, as well as supporting the development of cohesive Education Systems.

Finally, the assessment of performance trends over time offers policy-makers vital insights into which regions are progressing toward strategic goals and where disparities remain. With this dynamic, data-driven approach, policy-makers are better equipped to address performance gaps across the European regions, and thus promote targeted interventions to promote equitable educational outcomes.

Adaptive Policies for Dynamic Multi-Period Inventory-Routing Under Uncertainty

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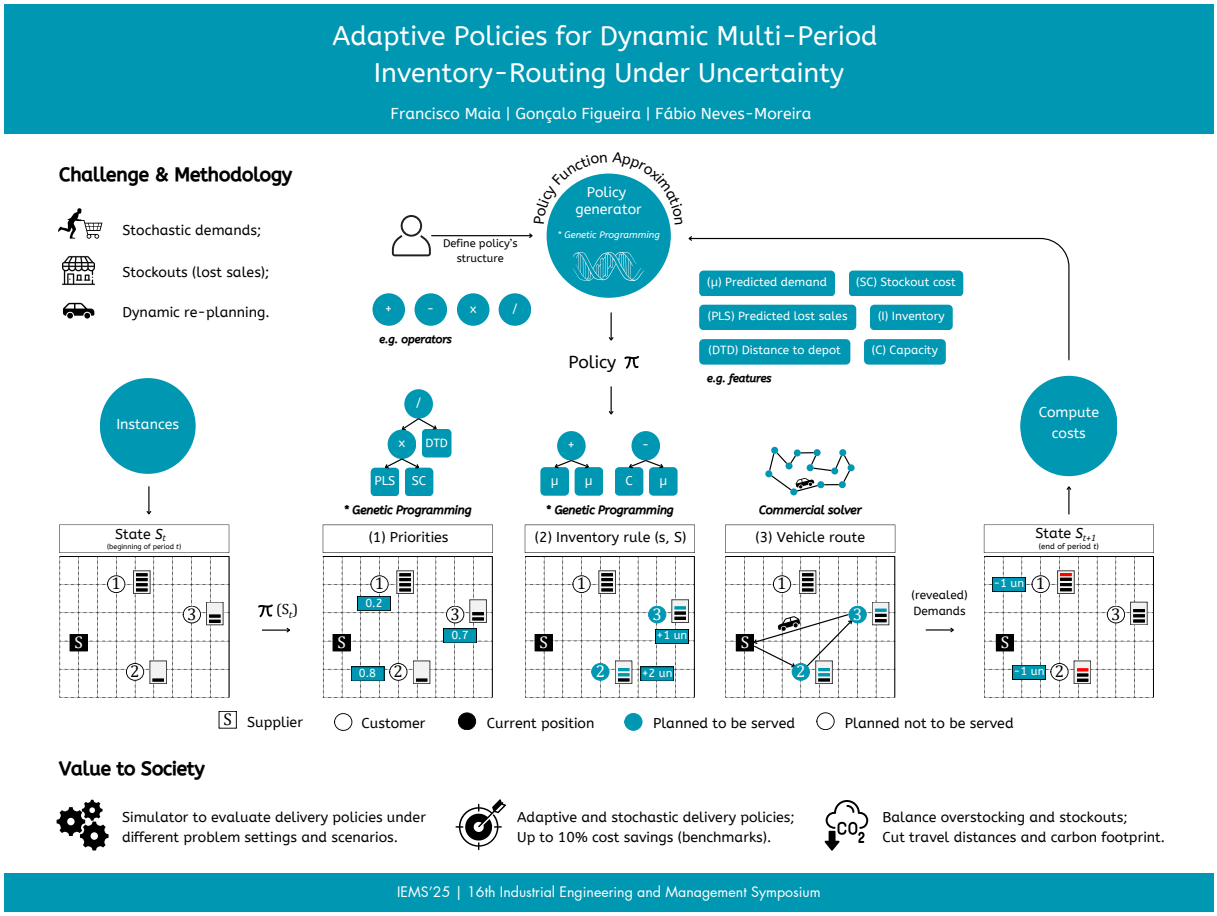

1 The Challenge

Integrating vehicle routing and inventory management has become a paramount and complex challenge within Supply Chain (SC) operations. Since the 1980s and 1990s, the scientific community has drawn attention to the Inventory-Routing Problem (IRP) in different sectors, including healthcare, retail, military, bike-sharing and waste-collection logistics. As an extension of the Vehicle Routing Problem, IRP integrates stock management, delivery scheduling and vehicle routing to minimise inventory and transportation costs over a planning horizon while ensuring a desired service level.

A common challenge SCs face is figuring out how to handle uncertainty effectively. In IRP, the primary sources of uncertainty stem from customer demands and travel times. These are typically represented by random variables, i.e., stochastic, following a probability distribution. Alternatively, they might be defined as fuzzy values, interval values, or no information at all is provided. Further, in real-world

operations, information models are dynamic, i.e., gradually disclosed over time, so continuous re-plannings are required to leverage the newly disclosed information and make informed and proper decisions.

The Dynamic multi-period IRP (DIRP), commonly understood as Dynamic and Stochastic IRP, refers to the joint optimisation of inventory and routing decisions under stochastic and dynamic environments. We considered a one-to-many structure in which a single supplier (e.g., central depot) replenishes a set of geographically distributed customers (e.g., retailers) with a single product. The planning horizon splits into T consecutive discrete periods: $t \in \{1, 2, ..., T\}$ that are solved accordingly. Periodically, each customer and supplier incurs a unitary holding cost. Stockouts may arise after demands are revealed at the end of each period. Moreover, shipments are performed by a single vehicle, resulting in distance-dependent costs.

Considering the challenge in modelling and solving the DIRP in real-time for large instances, a practical solution is no longer computing a static output but rather a decision policy that guides the evolution of inventory and distribution decisions based on the observed demands. The most elementary policies are myopic, i.e., based on short-term decisions without considering any information regarding future periods. These policies are typically applied in a rolling horizon fashion. On the other hand, proactive policies anticipate future demands through deterministic and stochastic lookahead models.

Lately, we have reported an upswing in combining Machine Learning and Combinatorial Optimisation methods to address the DIRP, given the promising results on similar dynamic and stochastic problems (e.g., vehicle routing and scheduling). However, it is also important to state that the effectiveness of policy-based methods, such as Policy Function Approximation (PFA) and Cost Function Approximation, can vary depending on the problem itself. In other words, the best approach may differ based on the available data. This research intends to give new insights into resolving the DIRP, where customer demands are stochastic and dynamically revealed over a finite planning horizon, so decisions must be released periodically.

2 The Methodology

As a dynamic problem, the DIRP with stochastic demands can be modelled as a sequential decision problem, more specifically as a Markov Decision Process. Given the flexibility in modelling stochastic elements by defining probabilistic transitions between states, we can compute policies that minimise the expected costs (i.e., holding, stockout and routing) over the planning horizon recurring to Approximate Dynamic Programming algorithms, i.e., PFA. Our methodology comprises four stages: (1) problem formulation, (2) simulator development, (3) feature engineering and data processing, and (4) policy generation and benchmarking.

In the early stage, we defined the current problem, including the optimisation decisions, objectives, and problem-solving methodology. The decision-making process assumes a three-step delivery policy: (1) calculate a delivery priority index for each customer; (2) determine the delivery quantities; (3) combine the previous customers into vehicle routes. Accordingly, each policy comprises a priority rule and an inventory replenishment rule (s, S), while a commercial solver computes the vehicle route by solving an instance of the Traveling Salesman Problem (see Figure 1).

In the second stage, a simulator was developed to mimic the stochastic and dynamic behaviour of the DIRP, as well as to enable the training and evaluation of a given policy under different scenarios. The simulator receives a set of instances as input, including the dynamic demands gradually revealed over the planning horizon and additional information (e.g., initial inventories, inventory capacities, holding and shortage costs, as well as further features from the third stage). All this information is necessary to compute the total inventory and routing costs.

The third stage focused on extracting and transforming critical features from instances (e.g., predicted lost sales, number of periods to stockout, distances customer-depot, vehicle capacity) that might be incorporated into the simulation process, contributing to flexible and accurate policies. Considering the scarcity of instances in the literature, an instance generator was developed to train and test the rules on a broad set of representative scenarios. Each instance is characterised by $n \in \{5, 10, 25, 50\}$ customers and $p \in \{10, 20\}$ periods. In order to evaluate our policies in highly heterogeneous scenarios, we analysed

multiple demand uncertainties, holding and shortage costs, and vehicle capacities. The resulting policies were also compared to several myopic and direct lookahead policies based on rolling horizon procedures with deterministic and stochastic forecasts.

The final stage involves policy generation, where policies are trained using Genetic Programming, an evolutionary algorithm that generates symbolic expressions that serve as policies.

3 The value to Society

Besides incorporating a policy generator that automatically generates novel delivery rules, our simulator allows us to replicate their behaviour before practising them in a real-world environment. Moreover, our simulator was designed to be easily adjusted and extended to different settings, including additional objectives regarding the Sustainable Development Goals 11 (i.e., sustainable cities and communities), 12 (i.e., responsible consumption and production) and 13 (i.e., climate action) adopted by the United Nations, as well as multiple items, and more complex networks. For instance, the routing costs, originally distance-based, could be adjusted to incorporate the carbon footprint. Consequently, the reward structure applied during the simulation-optimization procedure should be revised to reflect this consideration. In the meantime, the evolved policies overcome the benchmarks by reducing the total costs by up to around 10%, improving the balance between overstocking and stockouts, reducing wastes and decreasing the total travel distances.

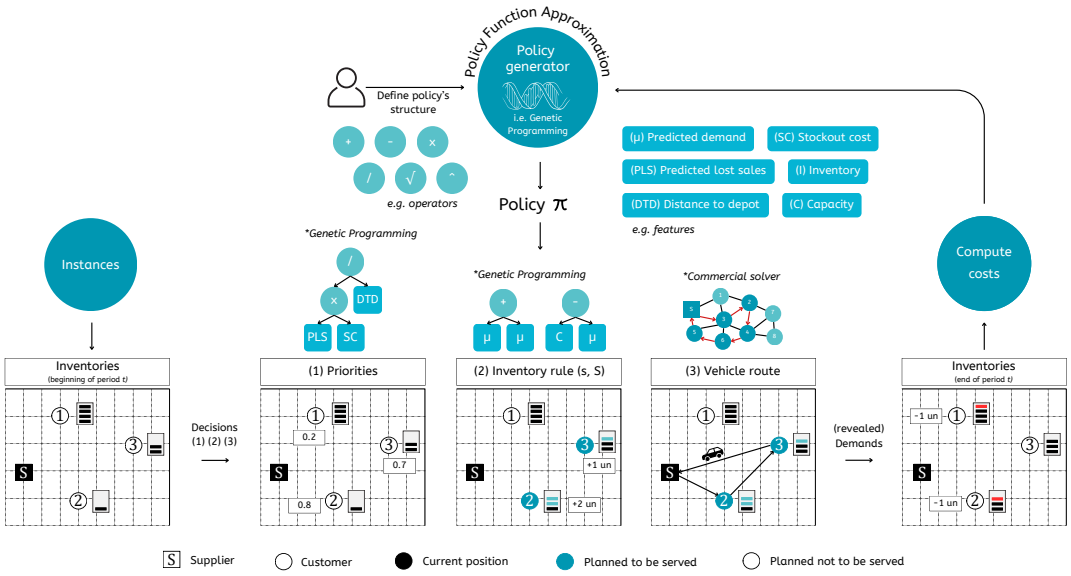

Figure 1: Problem-solving methodology (three-step policy)

Glass packaging capacity planning

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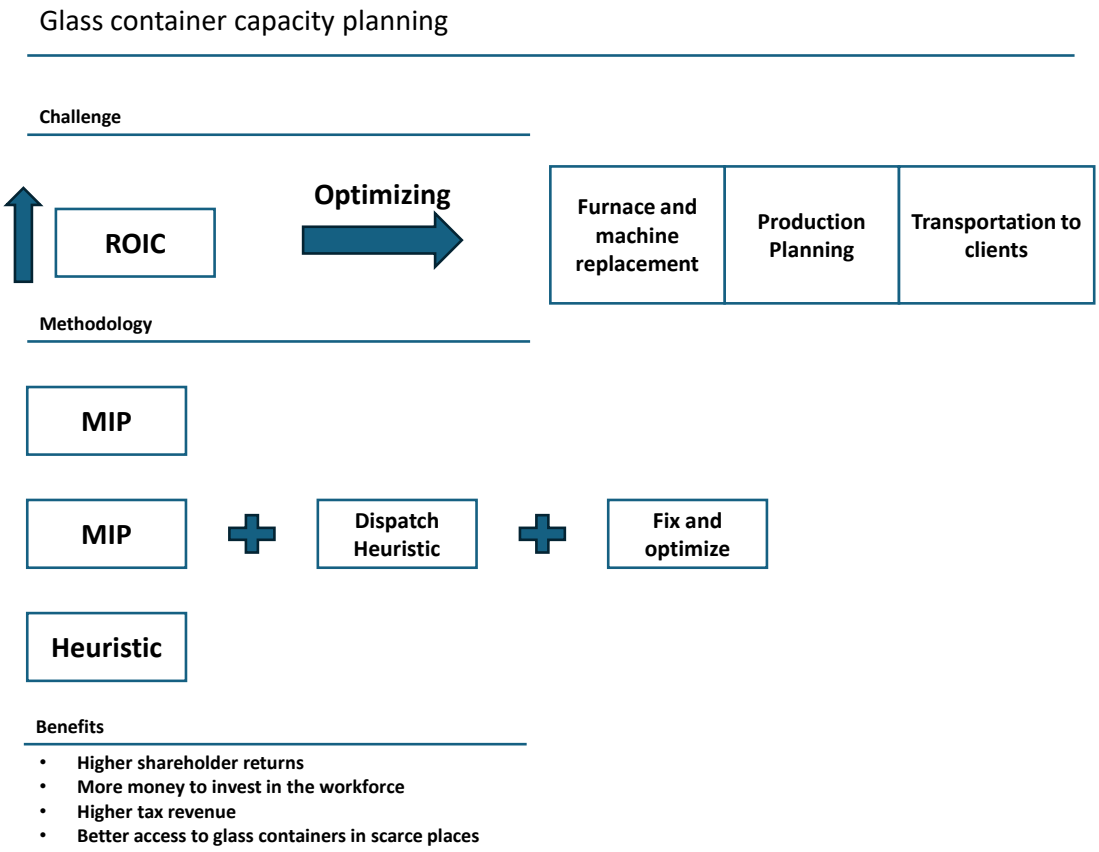

1 The Challenge

Currently, companies are facing higher interest rates, which means they must improve returns on invested capital to maintain the same performance and valuation. This is particularly important for capital-intensive sectors such as glass packaging, where a significant portion of revenue is reinvested in capital expenditures. Every ten years, the furnaces that melt the glass paste and the molding machines that shape it into its final form must be replaced. On average, replacing each furnace and its associated molding machines costs around 50 million euros, with each glass packaging company operating multiple furnaces. A key characteristic of the glass packaging industry is the lengthy setup times required to do glass color changeovers. This occurs because the furnace needs to operate for more than one day, melting the raw materials necessary to achieve the desired glass color. As a result, companies often run color campaigns, where inventory is built up, and certain furnaces are specialized to produce specific colors. This adds complexity, as there are multiple ways the furnaces can operate and various logistical paths the products can flow from the plants to the final customer. Additionally, each molding machine is associated with a fixed configuration. Machines with different configurations produce products at varying speeds. Each machine configuration also has specific restrictions on the products it can produce adding

more complexity to the problem. Considering the current economic conditions and the unique challenges of the glass packaging industry, this project seeks to improve the company return on invested capital through the development of a comprehensive model that optimizes color campaigns, furnace and machine replacements, and the transportation of finished products from plants to customers.

2 The Methodology

To address this challenge, a mixed-integer programming (MIP) model was developed, building on the long-term multi-facility glass container production planning model (MF-GCPP) with several modifications. While the MF-GCPP had a planning horizon of 2 to 3 years with monthly time buckets, the model in this project extends the horizon to 10 years, using quarter slots. Additionally, unlike the MF-GCPP, which kept furnace capacities and machine configurations constant, this new model accounts for furnace replacements near the end of their life cycle, allowing changes in both furnace capacity and machine configurations. The model incorporates a time window for furnace replacements and determines the optimal timing for each furnace replacement. To solve the MIP efficiently, a fix and optimize heuristic was introduced. This heuristic fixes the furnaces replacement periods, based on a dispatch heuristic, within the replacement time windows, and for each replaced furnace, a certain number of new machine configurations are fixed, while the remaining are free to be optimized. This approach breaks the MIP into smaller, more manageable problems, enabling better solutions in less running time. For larger instances involving 12 to 15 furnaces a heuristic is expected to be developed to provide good solutions within a reasonable time frame.

3 The value to Society

The model enables glass packaging companies to enhance profitability and increase free cash flow by offering an optimized and resilient investment plan. This reduces barriers to investment in countries with limited glass packaging capabilities. For instance, BA Glass, a Portuguese glass packaging company, is making substantial investments in Romania, a country facing scarcity in glass packaging, thereby improving access to glass-packaged products. By achieving greater profitability and having increased cash reserves, companies can enhance shareholder returns, invest more in their workforce, and contribute more to tax revenues, benefiting society as a whole.

Promoting Sustainable Resource Management through Charity Shops: A Behavioural Analysis of the Donation Flow of Goods

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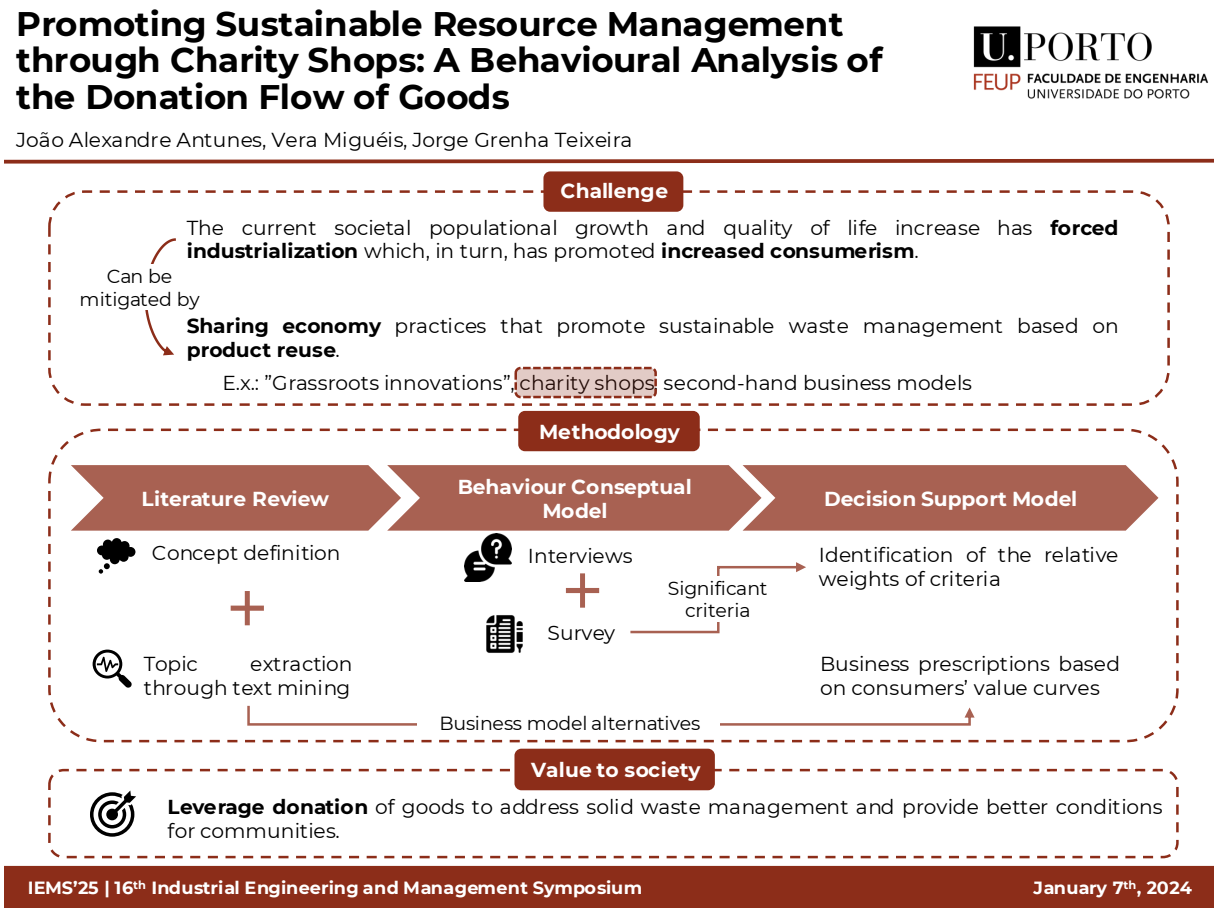

1 The Challenge

Modern societies have shown exponential population growth rates and quality of life increases. As a consequence of this, impending utilitarian and hedonic needs have put increasing pressure on industries, causing them to rapidly grow and adapt. Further motivated by economies of scale, the linear model of production and consumption has been established, promoting a consumerist lifestyle. As a result of this, waste production and idle resource quantities have been rising, making the current situation unsustainable in the long run. With the goal of escaping this dichotomy, research has been conducted in the fields of sustainable production and consumption, integrating different perspectives to develop sustainable solutions to the resource scarcity problem.

In this context, the concept of sharing economy has been gaining increasing relevance. The idea is facili-

tating access to goods and services through various business models. Within this concept, it is possible to find smaller initiatives aiming at driving sustainable transitions, called "grassroots innovations". These are smaller networks of activists and organizations that develop bottom-up approaches towards sustainable development. As far as product types go, "grassroots innovations" can go from specific, such as community composting schemes to mitigate organic waste disposal, to broad, as is the example of freecycle networks that aim at promoting the exchange of diverse items. However, due to their nature, these initiatives hold an unstructured and informal basis.

Contrasting to "grassroots innovations", on a larger scale, some organizations have been either created (e.g., Vinted) or changed their business models (e.g., Zara) to incorporate the re-use of products. However, since these business models attend to an international community, items are often transported across large distances. In these cases, the environmental benefit obtained from acquiring a second-hand item is offset by the logistics costs associated with its transportation.

Charity or thrift shops fall in between "grassroots innovations" and large scale organizations. Combining the community network of the "grassroots innovations" with the scalability of larger organizations' business models, charity shops obtain their stock, for free, from a network of donors, which can be either individuals or organizations, later selling it at a very low price. With this, charity shops promote the reuse of products, actively tackling issues of resource scarcity. The profits obtained from the charity shops' activities are then used to support beneficiaries. One topic of charity shops' research that has been under-researched is their position in the supply chain. Considering the fact that the functioning of these shops rely heavily on donations, understanding these and the underlying behavioural dynamics is crucial. It is then mandatory to understand what are the drivers and/or barriers to the donation process and how these are perceived by individuals. Furthermore, knowledge about the relative importance of these factors can enable charity shops to better address the network they are inserted in, ultimately leveraging donations.

2 The Methodology

The literature on the sharing economy is fairly recent and ever-growing. To get a better grasp on current research trends, a literature review will be conducted. As indicated by previous research, the concepts underlying the sharing economy are still underdefined. Therefore, the first objective of the literature review will be to summarise existing concepts and their definitions and organize them in a framework representative of the sharing economy. Moreover, advanced data analytics such as text mining will be employed to identify and characterize the main research trends. From this, future research directions will emerge, guiding future work to effectively address all aspects surrounding charity shops, "grassroots innovations" and other business models, leading to more sustainable waste management.

Afterwards, focusing on behaviour, to understand what factors drive donation behaviours a mixed methods approach will be taken. In the first place, to identify what possible aspects people may consider when considering donating their items, interviews will be conducted. The factors identified during the interviews will then be used to develop a model that will be evaluated through a survey and validated using statistical methods. With this, we aim to provide guidelines to charity shops about which aspects they should consider and focus their attention when promoting their activity to better leverage donations.

Lastly, to provide further recommendations to charity shops, a study will be conducted based on decision-support models. Considering the factors identified in the previous study as possibly influencing donation behaviours (e.g., moral norms, economical benefits, collection systems, etc.), the evaluation criteria will be set. Furthermore, the construction of the alternatives will be based on the information found in the literature review about business models in the sharing economy. Following a methodology based on Multi-Attribute Value Theory, it will be possible to determine the relative importance of the criteria and establish a value curve for each one. Leveraging this approach, charity shops will first be able to prioritize the criteria to focus on and, secondly, decide on the most advantageous business characteristics to maximize donations inflow.

3 The value to Society

Charity shops provide an alternative stream for waste management. By collecting and reselling used items, not only their lifetime is extended but they are also diverted from landfills or other ends. Considering this, understanding what factors drive individuals towards donating their items, whether it is to charity shops or others, constitutes extreme importance in reducing waste production. Ultimately, promoting donations of goods, which then enable second-hand consumption, is one alternative to managing municipal solid waste, actively addressing SDGs 11 and 12.

Charity shops, as non-profit organizations, have at their core the redistribution of any profits to beneficiaries. Considering this, ensuring the inflow of items will, to some extent, ensure their sale. This not only contributes to facilitating the access to cheaper items by those in need but also results in higher contributions to beneficiaries. Therefore, by contributing to the better functioning of charity shops, this work helps provide better conditions to the communities and, consequently, address SDG 10.

Considering the aforementioned points, this research plays a part in promoting circular economy by the re-circling of goods, especially for those in need, fostering economic resilience within communities. Moreover, it also enhances community support and engagement, strengthening social ties.

Using Gen-AI for developing strategic foresight

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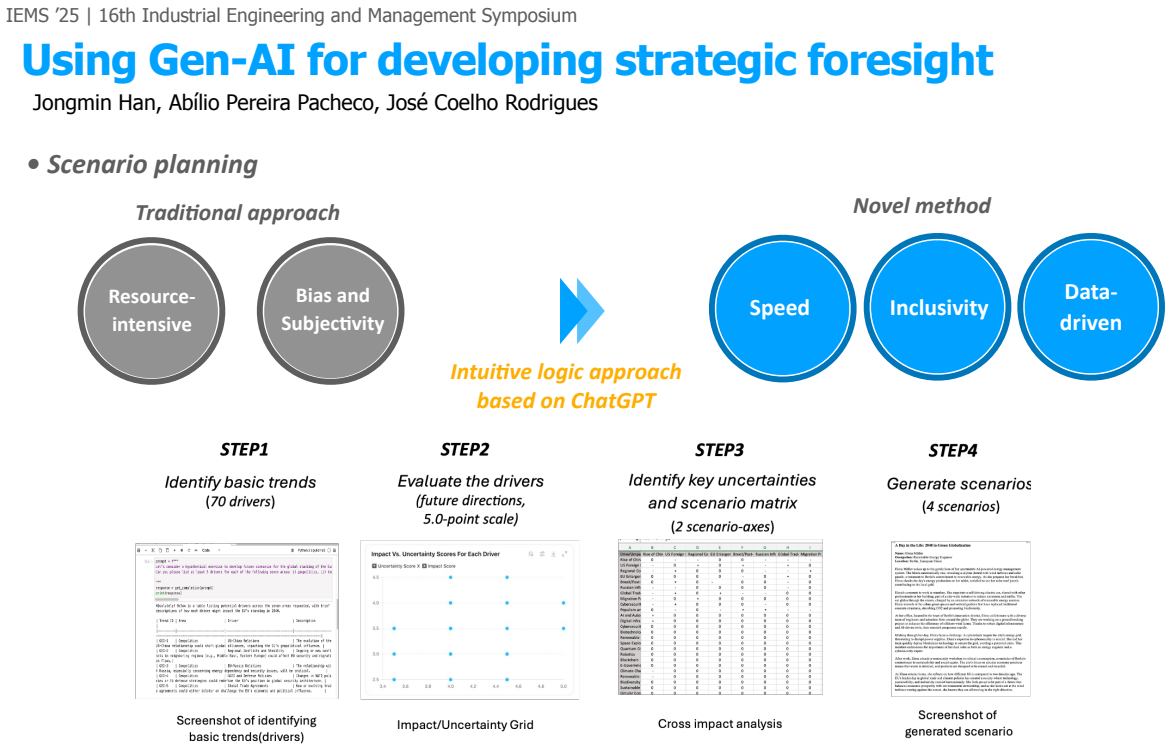

1 The Challenge

Companies and governments use forecasting methodologies to prepare for potential obstacles that may arise in the future. One such method is scenario planning, which involves creating hypothetical scenarios based on different variables and factors. Decision-makers analyze these scenarios carefully to understand potential outcomes and make informed decisions. This process helps ensure they are well-equipped to handle any disruptions that may occur. However, traditional scenario planning is often limited by its time-intensive process and subject to new pressures from unpredictable events requiring immediate attention.

The most commonly used method in traditional scenario planning is the workshop method based on an intuitive logic approach, where experts or stakeholders from various fields draw conclusions through discussion and agreement. While this method effectively reaches an agreement among participants, it has certain drawbacks. These include being time-consuming, resource-intensive, and lacking an objective verification process. Additionally, scenarios derived from workshops may interpret the future

differently due to participating experts' varying perspectives, knowledge levels, and personal interests. Thus, analyzing uncertainty and predicting futures may be limited by the expert's knowledge domain. Generative Artificial Intelligence (Gen-AI) offers exciting opportunities to overcome these limitations and enhance productivity. Gen-AI can promptly create more nuanced and varied scenarios by integrating vast amounts of data and identifying patterns that humans might overlook. This means that decision-makers can quickly anticipate and respond to potential challenges and explore various previously inaccessible or overlooked alternatives.

2 The Methodology

We propose using an intuitive logic approach that includes the scenario-axes technique, a traditional scenario planning method, to enhance the reliability and validity of the scenarios in ChatGPT. The scenario-axes technique, based on the impact/uncertainty grid and cross-impact analysis, can align divergent views on how the future may unfold. This technique allows exploring the unknown to become a relatively structured and coherent activity.

The impact/uncertainty grid is integral to identifying and categorizing factors that could significantly influence future scenarios. It works by positioning factors along two axes: one for impact (how strongly a factor can shape outcomes) and one for uncertainty (how predictable the factor's behavior or influence is). By placing each factor on this grid, decision-makers can prioritize highly impactful but uncertain elements, which often reveal key areas where different future outcomes may diverge. This process helps reduce scenario complexity by narrowing down essential drivers that deserve closer analysis, making the scenario generation process more focused and streamlined. For ChatGPT-based scenarios, utilizing the impact/uncertainty grid enables the model to concentrate on high-priority, high-uncertainty factors, improving the relevance and depth of its scenario narratives.

Cross-impact analysis is a structured approach to exploring how trends, actions, or variables interact and influence each other. This technique evaluates the potential causal relationships between factors, often represented as a matrix that shows how one factor's outcome might change based on another's influence. Cross-impact analysis provides insight into dynamic interdependencies, enabling ChatGPT to generate scenarios that consider cascading effects and interconnected variables. By implementing cross-impact analysis in ChatGPT's scenario generation process, the AI can better reflect complex causal relationships, resulting in richer, more plausible scenarios.

These methodologies enable the systematic categorization and analysis of variables and trends essential for robust scenario generation, helping ChatGPT produce more consistent and reliable scenarios. To further improve consistency, additional strategies are recommended, including prompt refinement, model parameter adjustments, and iterative review using ChatGPT. Prompt refinement involves structuring inputs to guide ChatGPT in generating relevant, coherent narratives. Model parameter adjustments, such as temperature tuning, play a critical role in controlling the creativity and variability of outputs. Temperature settings influence the randomness of responses, with lower temperatures yielding more focused, deterministic outcomes, and higher temperatures introducing variability, allowing for broader, less predictable scenarios. Adjusting the temperature parameter enables ChatGPT to align with the desired level of uncertainty in each scenario, offering decision-makers the flexibility to explore both predictable and novel future pathways.

Finally, an iterative review process using ChatGPT further cross-validates the generated scenarios for coherence, relevance, and strategic alignment. By integrating these strategies with the scenario-axes technique, impact/uncertainty grid, and cross-impact analysis, we can create a more structured, credible approach that aligns AI-generated scenarios with the needs and expectations of decision-makers.

3 The value to Society

This study integrates Gen-AI with traditional scenario planning techniques, enhancing societal resilience by enabling quicker, more inclusive, and data-driven preparedness for unpredictable events. Gen-AI's ability to analyze extensive and diverse data sources allows for the generation of a wider range of scenarios,

enabling decision-makers to consider perspectives that traditional methods might overlook. This leads to more equitable and informed policies in sectors such as healthcare, environmental protection, and public safety. Furthermore, the efficiency of AI-enhanced scenario planning makes robust strategies accessible to smaller organizations and local governments, empowering them to make proactive, data-informed decisions. This adaptive and iterative approach fosters a culture of transparency and accountability in decision-making, ultimately creating a more agile and resilient society that is better equipped to handle future challenges effectively.

Unified Framework for Sizing Hybrid Renewable Energy Systems with O&M Factors

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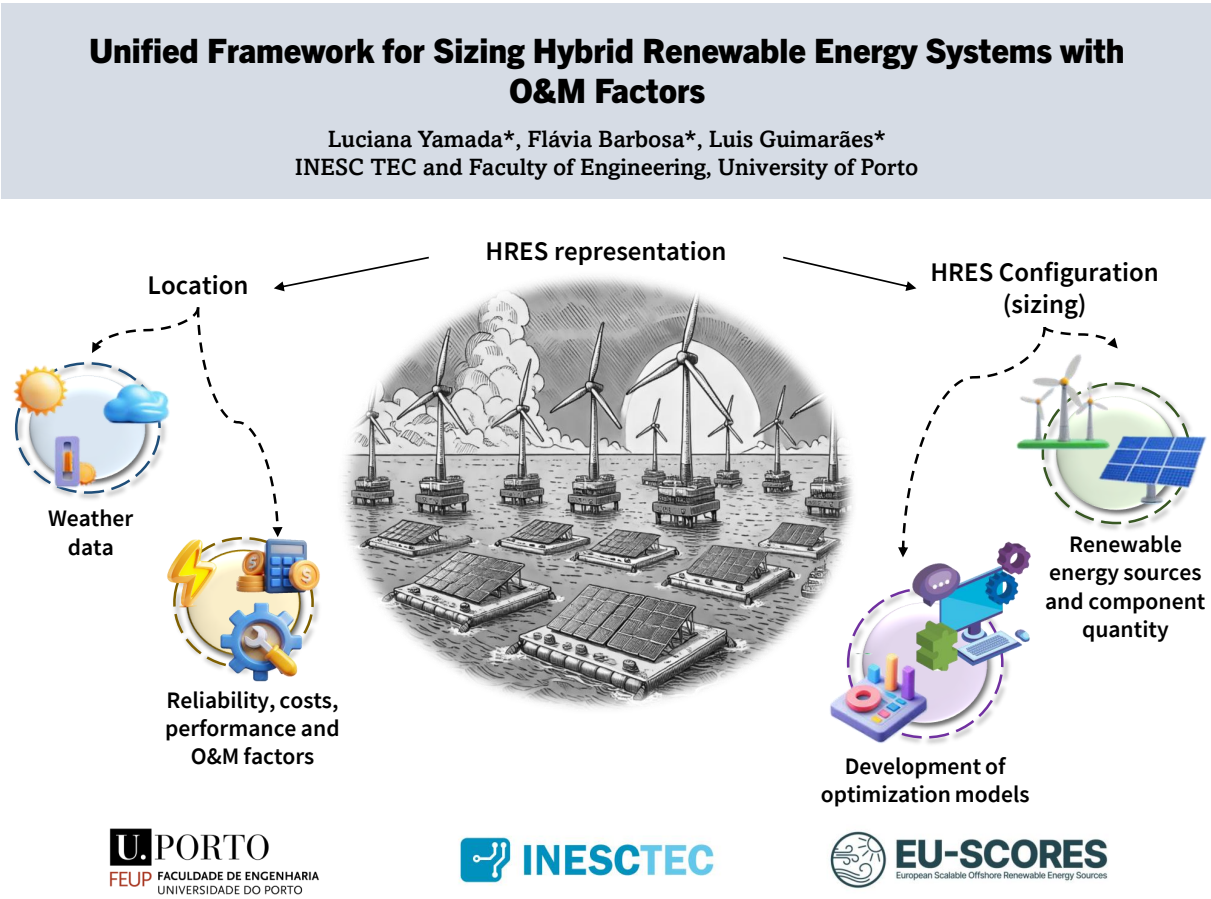

1 The Challenge

The integration of different renewable energy sources (RES) into hybrid renewable energy systems (HRES) has garnered significant attention for its potential to enhance energy system reliability. Integrating different energy sources improves energy supply stability by mitigating the effects of source variability and enhancing overall performance. It also optimizes land use and reduces costs by sharing expenses throughout the project's lifecycle, which includes operational and maintenance (O&M) activities, electrical infrastructure, and space leasing.

There has been a noticeable increase in investments in HRES projects, as well as in existing energy parks, to hybridize with new energy sources. In this context, the design of HRES becomes essential for creating efficient solutions. To hybridize an existing energy park or develop a new one, the goal is to balance the initial capital investment and operational expenditures while ensuring system reliability. Achieving this

balance requires a realistic representation of the system, along with the development of precise models to evaluate long-term benefits and design outcomes.

The primary challenge of this work is to achieve a realistic representation of the HRES. HRES in offshore environments are highly affected by weather conditions (e.g., wave height and wind speed), which can impact energy production, O&M costs, and park revenue. O&M costs in an offshore park can account for approximately 30% of the total project costs. Therefore, a realistic representation must consider O&M factors such as equipment availability, accessibility, failure and repair rates, as well as energy production profiles, and associated investment and maintenance costs. Determining the system's optimal sizing (number of components and type of energy) is crucial to ensure efficient performance and economic viability. By integrating these factors into the design of HRES, a comprehensive understanding of the system's behavior can be attained. A secondary challenge arises from the complexity of modeling and incorporating these factors into the system representation: the development of efficient optimization algorithms. These algorithms are essential for generating high-quality solutions, thus enabling the effective design and operation of HRES.

2 The Methodology

This work presents an optimization framework for HRES design that incorporates O&M factors to estimate system performance accurately while identifying the most cost-effective configurations to enhance investor returns in two strategies: hybridizing an existing park or expanding the parks with the same installed energy. Four offshore wind farm locations in Europe have been chosen to test the methodology. These locations vary in several aspects, including installed capacity, number of turbines, price of energy, maximum capacity of export cable, and the potential for wind and solar energy. These locations were selected to provide insights into how their characteristics can influence system sizing and why the chosen strategy – hybridization or expansion – is the most profitable option for the park. The HRES design optimization framework consists of three main elements: the optimization model, power calculation modeling, and availability modeling. Power calculation modeling is a pre-processing step, while availability modeling is integrated into the optimization model using the expected power variable.

The optimization model is a mixed integer nonlinear programming that uses the net present value (NPV) indicator and the capacity energy constraints that are applied to the problem. NPV measures the present value of future cash flows, considering the value of money over the project's lifetime. This economic indicator is calculated using the annual cash flow subtracted from the investment costs in the system and adjusted by a discount factor. The decision variables of the model rely on the total energy sold (continuous variable) by the HRES and the type and number of equipment (integer variable) used in each technology. Regarding the constraints, the locations have a maximum capacity for delivering energy through the export cable. While the total energy produced by the system can exceed this maximum capacity, the total energy sold must remain within the limits of the cable's capacity. Other constraints are introduced to the model to discretize the decision variable. The model's nonlinearity arises from the expected power variable calculated using the availability model, which depends on the decision variable of the number of components.

The power calculation outlines the modeling approach for the two technologies employed in this study – wind turbines (WTs) and photovoltaic (PV) panels. The power equations are based on the power curve of WTs and technical parameters from PV manufacturers. While this study focuses on these specific technologies, the framework must be sufficiently flexible to incorporate other technologies.

The availability is modeled through a mathematical tool called the Markov process, which mainly aims to model the states of a stochastic process based on transition rates or probabilities. The model considers the total number of components (decision variable of the optimization model) as the states and the frequency with which they can fail (failure rate) or be repaired (repair rate) as the transition rates. Therefore, the system's availability, which represents the proportion of the time that a component is operating, can be modeled and used to estimate the total expected power output. Moreover, the effects of maintenance actions and weather delays on system performance are incorporated through an accessibility factor integrated into the availability model. This approach allows accurate system performance estimation, considering downtime and associated financial losses while the configuration is analyzed.

3 The value to Society

This work supports improving clean energy systems and providing environmental and economic value to society. Investing in a 100% renewable energy system is essential to reduce dependence on fossil fuels and to achieve a net-zero emission economy. This work contributes directly to Sustainable Development Goals 7 (Affordable and Clean Energy) and 13 (Climate Action) within the Sustainable Development Agenda. In economics, lowering electricity costs by combining the sources and achieving cost savings in O&M activities can lead to reduced energy expenses and a more stable energy supply. The overall capital expenditure per MW installed in HRES is expected to be reduced by sharing the electrical infrastructure cost and delivering the power through a combined export system to land. The shared use of vessels also expects reduced operational expenditure and O&M teams trained and equipped to handle the different technologies. Therefore, the complementarity of RES, leading to a continuous and increased overall power output, can raise the revenues of the HRES operator compared to offshore wind parks. Furthermore, demonstrating the cost competitiveness of an HRES can validate its potential as a feasible techno-economic solution, helping deploy these systems on a large scale.

Related Diversification and its impact on Research & Development and Innovation

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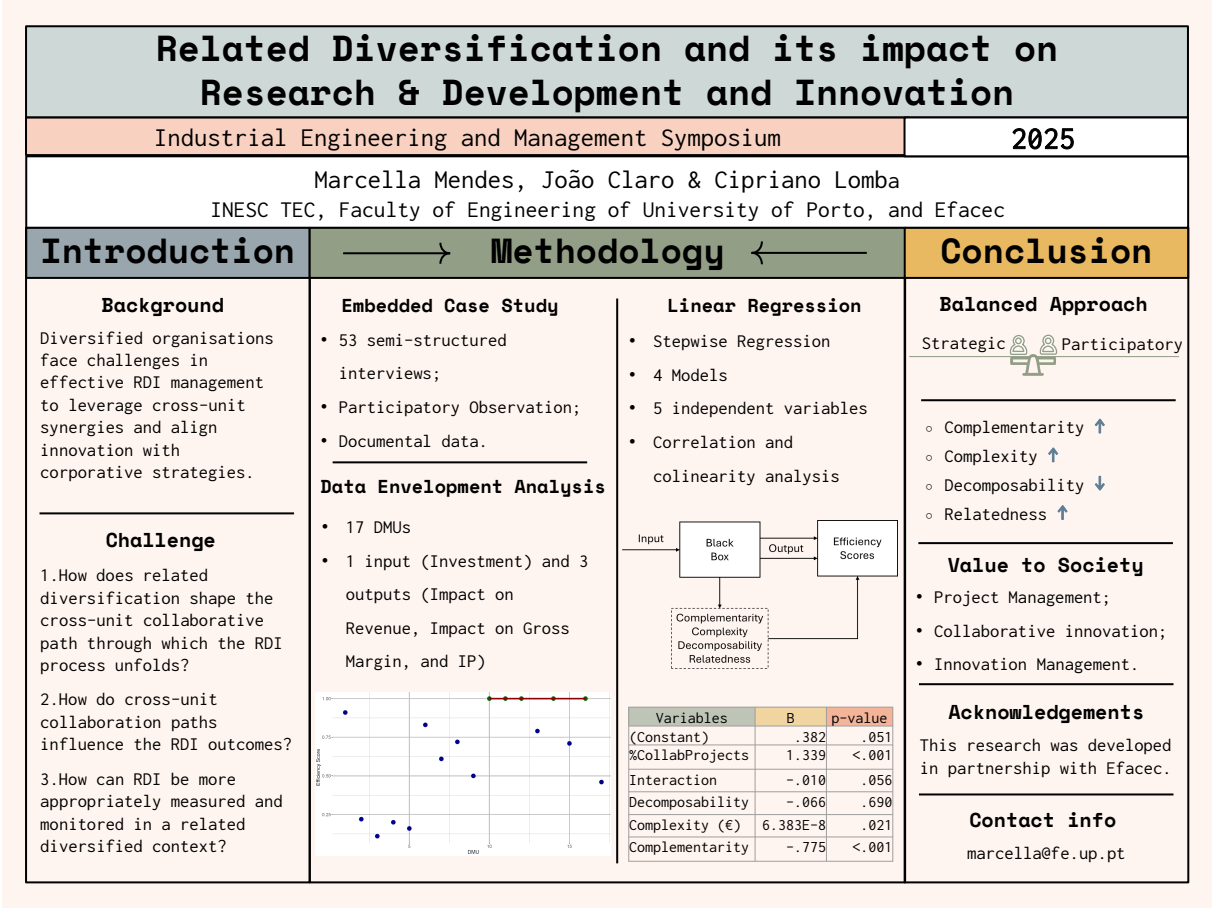

1 The Challenge

Diversified companies with related business units (BU) face specific challenges regarding innovation management. They need to monitor and assess their performance effectively while exploiting synergies among their different BUs and coordinating collaborative projects to maximise the value and returns on their research and development (R&D) efforts for enhanced innovation performance.

The first challenge for our research was understanding the specificities of related diversification that can shape the path of collaborative work during the RDI process and their influence on its outcomes, which can consequently impact innovation performance. Our results show that the nature and direction in which the ideas arise are critical factors in determining the effectiveness of Research & Development and Innovation (RDI) activities within this context.

In particular, ideas initiated by the corporate level often guide RDI more strategically, ensuring close alignment with the organisation's goals. On the other hand, ideas formed at lower levels of the organisation encourage a more collaborative method when they move up to the corporate level, leveraging the

valuable perspectives and know-how of individuals involved in daily tasks. This complex interplay shows how related-diversified organisations balance top-down strategic guidance and bottom-up innovation efforts. Therefore, a deep understanding of this interaction is essential for effectively measuring innovation efficiency in a related-diversified company, as it encompasses the impacts of both the corporate level and the BU perspectives necessary for the innovation process.

Another challenge consisted of identifying an efficiency measurement method to evaluate innovation in this context. For this, it was crucial to recognise the influence of different contextual factors on innovation efficiency, such as the relatedness among BUs, the level of interpersonal interactions, the complexity of current projects, and the ability to break down complex tasks. In order to achieve this goal, we employed Data Envelopment Analysis (DEA) to evaluate the efficiency of innovation and Linear Regression to understand the impact of contextual variables.

2 The Methodology

In our study, we employed a comprehensive methodology to investigate the relationship between the specificities of related-diversified contexts, their impact on RDI pathways, and innovation efficiency. We conducted 53 semi-structured interviews, complemented by participatory observation and the gathering of documental data, as part of an embedded case study of a related-diversified company, which provided us with insights and a comprehensive understanding of innovation dynamics in this context. This first part of the research highlighted the influence that the direction of idea generation bears on RDI processes and outcomes. After the embedded case study phase, we used DEA to quantitatively evaluate innovation efficiencies across various BUs. This analysis allowed us to assess how adept these units are at converting available resources and inherent capabilities into innovative products, services and processes, thereby establishing benchmarks for performance evaluation.

We also employed linear regression techniques to deepen our analysis and examine how various contextual factors (complementarity, complexity, decomposability, and relatedness) influence innovation efficiency. We considered a range of dimensions, such as the degree to which different BUs complement each other's competencies, the proportion of collaborative projects relative to overall projects, and additional variables, including the frequency of team interactions, the complexity of the projects undertaken, and the ability to break down complex tasks into smaller, more manageable components.

By integrating these methods, we aimed to present a clear, complete perspective on how the most significant specificities of the related-diversified context can influence innovation outcomes. Preliminary findings indicate that while a top-down approach provides clear strategic direction, it can suppress BUs' creativity, empowerment, or autonomy. On the other hand, bottom-up initiatives, while promoting inclusion and broad participation, may need guidance for rapid decision-making in the diversified context to be well aligned with corporate strategy.

3 The Value to Society

The implications of our research are relevant across multiple levels, from individual organisations to broader economic contexts, offering valuable insights for stakeholders at each scale. By clarifying the dynamics within collaborative RDI processes, our study offers important insights into innovation and project management for policymakers, industry leaders, and academics. It emphasises the potential advantages of integrating top-down strategic initiatives with bottom-up participatory processes, a synergy that, if further leveraged, could enhance innovation ecosystems and project management frameworks.

Our research highlights the need for better decision-making practices, tailored to the complexities inherent in diversified contexts, particularly in organisations with multiple business units. By specifying how distinctive contextual characteristics shape RDI pathways and their outcomes, we highlight the importance of recognising these dynamics for a more accurate understanding and effective orchestration of innovation.

Furthermore, the insights obtained in this study can empower decision-makers and project managers

to strategically navigate the complex RDI processes present within diversified environments, eventually leading to enhanced innovation performance. By cultivating a culture of balanced decision-making, organisations can take advantage of diverse perspectives that are fundamental to advancing knowledge, creating technology-based products, services and processes, and promoting broader economic and social progress.

Also, the research featured significant variations in innovation efficiencies across the BUs, as determined through the DEA application. This analysis enabled us to identify which BUs achieved the highest levels of innovation performance, offering insights into effective practices that could be replicated in other units within the company. Moreover, the linear regression analysis indicated that contextual factors, such as task decomposability and complexity, significantly impact innovation efficiency. Specifically, we found that higher decomposability often negatively affects efficiency due to the increased need for integration and coordination among BUs. Conversely, variables like complementarity and relatedness were positively correlated with efficiency.

This research emphasises the need for a balanced mix of strategic and participatory approaches when fostering innovation in diversified contexts. Achieving such balance is essential for successfully navigating synergies, coordinating anti-synergies and complexities, and ensuring sustained growth and development in such environments. Furthermore, the findings emphasise the importance of customizing organizational structures and management practices to the unique context of each business unit, thereby enhancing the approach to promoting innovation more effectively.

Functional asset management through data processing

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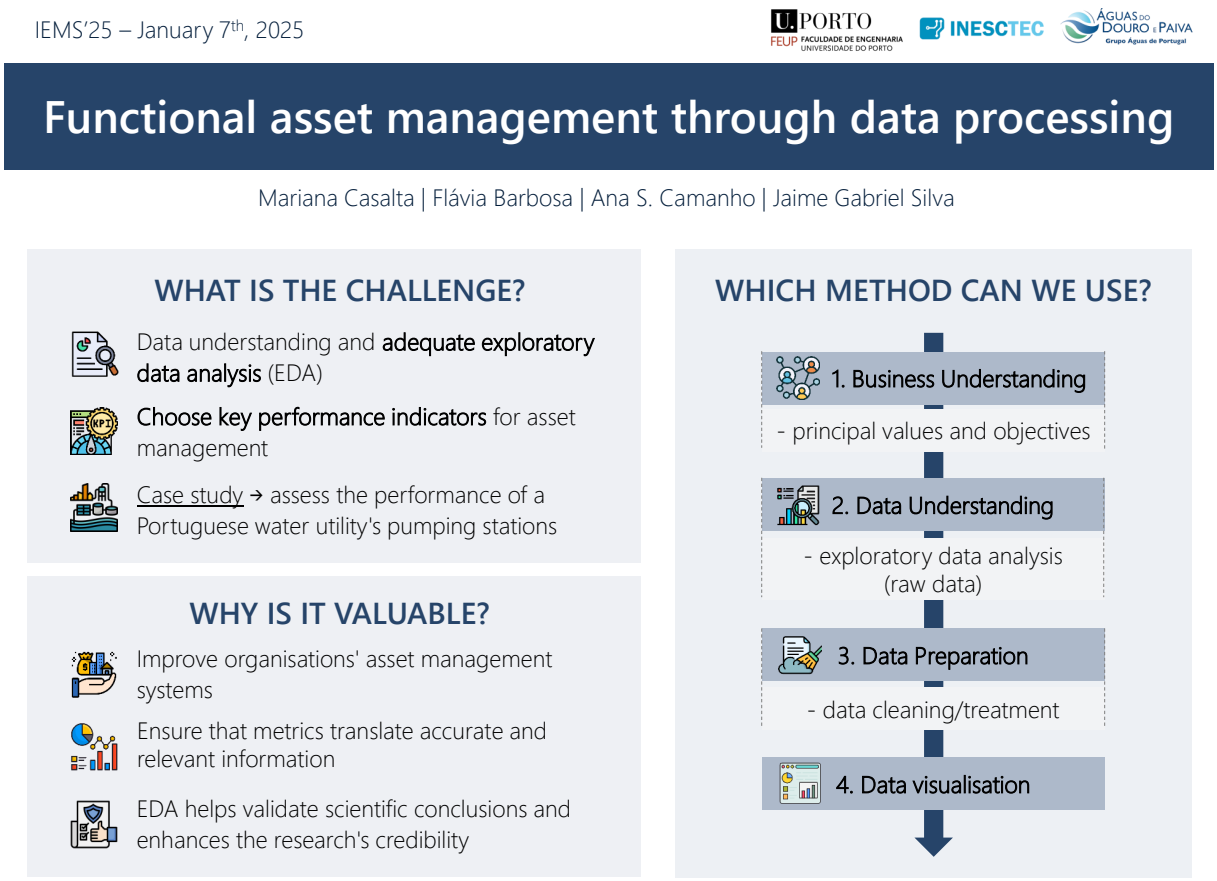

1 The Challenge

Water utilities face challenges when choosing the most appropriate key performance indicators (KPIs) for managing their assets. Their decision-making is centred on asset management principles to meet organisational objectives and obtain better returns. Therefore, it is essential to understand all the data and prepare it appropriately for analysis. Adequate exploratory data analysis (EDA) allows for maximising the value of data, leading to the identification and extraction of significant patterns in the data and quality results.

This study aims to establish the best metric for assessing the performance of a Portuguese water utility's pumping stations (PSs) and to compare them. Choosing KPIs for asset management can allow businesses in all industries to improve decision planning. Combined with objectives and goals, KPIs help organisations find problems at any point in the asset's life cycle, and this concept can support tracking patterns over time and measuring progress. KPIs can help to identify the asset management factors that require

improvements. Because tracking the wrong KPI for the wrong industry or reason can give an incorrect picture of business management, wisely choosing what KPIs you should track for asset management is essential.

In this sense, collecting and processing relevant, quality information is a big challenge in data science. It is essential to filter all the information available and choose the data that best reflects the issues we are evaluating.

2 The Methodology

Data science is an interdisciplinary field that deals with a large volume of data and uses methods and processes to extract knowledge and insights from data. It is an area that combines principles of statistics, computer science and specific knowledge of the application area to collect, process, analyse and interpret data to solve complex problems and support decision-making.

This work portrays the importance of data processing for the effective control and management of an organisation's assets. Figure 1 schematises the main stages of the proposed methodology. The first stage of the methodology consists of understanding the business, i.e., the organisation's principal values and objectives. The following stage is data understanding, where EDA is carried out. It is a significant step that should be part of data science projects in every organisation to ensure the data is what it is claimed to be. All the relevant information from the organisation's different data sources is gathered at this stage. Next, the information that is relevant to the case study being analysed is filtered out.

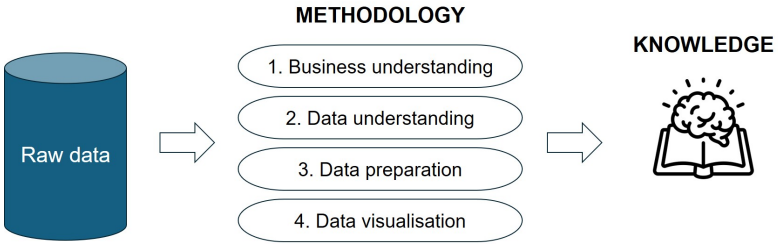

Figure 1: Main stages of the proposed methodology.

In most cases, the information is unstructured or semi-structured data. Therefore, the data needs to be treated so that it can be analysed and modelled. Consequently, the third stage of this methodology begins, the data preparation phase. Firstly, the data is cleaned since outliers and missing values affect the quality of the results.

In general, outliers should be dealt with first, as deciding whether they belong in the data is necessary. Next, there are two ways to deal with missing values: remove the entire observation or impute a value. Imputing missing data (for example, by mean or regression) should be done after dealing with outliers since imputing data distorts the variance and interquartile range. Once the data has been cleaned, it needs to be normalised to make it easier to compare and analyse. Finally, the data's final validation must be performed to check the quality and integrity of the processed data.

Once the data is ready to be analysed, visualisation techniques can be implemented to make conclusions about the data. Graphs are fundamental to the EDA because the rich information they provide is unrivalled in their ability to detect data patterns. They allow us to evaluate different assumptions and analyse if a model fits the data poorly. These techniques help uncover data characteristics that can complement confirmatory analyses.

The methodology was developed in conjunction with a water utility. The first stage consisted of understanding its business activity and, in more detail, the operation of the PSs. The PSs are high-value infrastructures that lift water to several locations and must be managed efficiently. The second stage was to understand all the information collected about these infrastructures.

According to the ISO 55000, proper asset management seeks to achieve the desired balance between cost, risk and performance to recognise and produce value. In this sense, the information about the PSs was filtered, and only data covering these three factors was analysed. In particular, data was collected on the operation of the PSs over the last eight years: number of unplanned occurrences and breakdowns, downtime, operational costs and energy consumed for pumping, considering the volume pumped and the manometric height of the PSs. Finally, we prepared the data and implemented visualisation techniques to analyse the data compiled.

3 The value to Society

The relevance of this study is justified by the urgent need to establish processes to improve asset management in water systems. Water utilities regularly face challenges associated with the degradation and ageing of infrastructure. The serious consequences of failures or leaks can lead to damage or breakdowns in adjacent infrastructures, such as roads, oil or gas distribution systems, besides the direct effects of water supply shortages.

Furthermore, the water sector is a capital-intensive industry, involving high-value infrastructures and requiring large investments. Therefore, it is essential to implement effective asset management systems that allow proper assessment of the assets' condition in order to predict and prevent undesirable future events.

Efficient asset management requires the appropriate selection of metrics. To this end, EDA is one of the most important stages in this process and is fundamental to the success of asset management in organisations. Exploration is essential to the scientific process and helps establish the validity of scientific conclusions. Consequently, EDA and its ability to detect patterns play an important role in enhancing the credibility of organisational research.

To ensure that metrics translate accurate and relevant information is a complex task. If not undertaken correctly, it can have serious repercussions on asset management, jeopardising the success of the business. In addition, the monitoring of these measures must be effective and capable of providing feedback on the implementation of strategies, guiding decision-makers and driving the evolution of sector policies.

The Portuguese water utility under study had never carried out an EDA. After implementing the proposed methodology, the utility realised that extracting knowledge from the data collected daily is possible. Correct data processing is one of the most critical and complex tasks in managing an organisation's assets. In this regard, the methodology presented converts the information collected by utilities into treated data. In this way, the data is ready to be modelled and used as inputs in other analyses and decision-making processes.

Incorporating substitution effects in demand forecasting for perishable products

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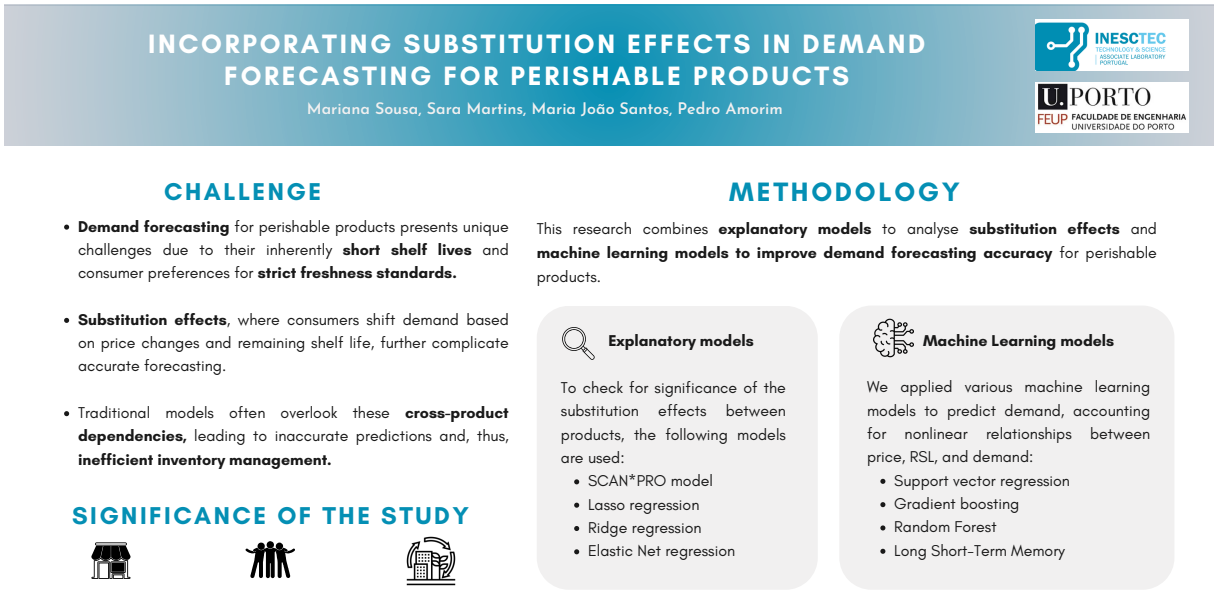

1 The Challenge

Demand forecasting is a vital aspect of retail operations, significantly influencing inventory management, supplier coordination, and customer satisfaction. In the context of perishable goods, the importance of accurate forecasting is even magnified due to their rapid deterioration and limited shelf life. The freshness of these products is a crucial factor influencing consumer preferences, resulting in considerable fluctuations in demand as items approach their expiration dates. To reduce spoilage and minimize revenue loss, retailers in this sector must ensure predictable stock levels.

Despite the extensive literature on demand forecasting, most research primarily focuses on predicting demand for individual, non-perishable products. This narrow approach often overlooks the complex interactions among substitute items and fails to consider the impact of remaining shelf life on demand, thus limiting the ability to capture actual demand patterns and interdependencies. Furthermore, while substitution effects between distinct brands have been thoroughly investigated in marketing literature, the analogous effects related to freshness have received insufficient attention in the field of operations research concerning perishable food.

This study aims to address these gaps by developing a demand forecasting model incorporating substitution effects specific to perishables. Specifically, we investigate how price and remaining shelf life variations influence the demand for similar items and develop an algorithm capable of forecasting demand across multiple products while accounting for substitution dynamics.

2 The Methodology

This research employs a two-phase methodology, beginning with traditional statistical approaches and progressing to machine learning models. First, an extended SCAN*PRO model is utilized to estimate price and remaining shelf life cross-elasticities. This model serves as a benchmark for evaluating the degree and nature of substitution effects in perishable goods.

Next, we apply regularized linear models, specifically Lasso, Ridge, and Elastic Net regressions, to manage multicollinearity and improve model interpretability through feature selection and coefficient shrinkage. These models help assess the significance of substitution effects across all products.

In the second phase, we focus on the forecasting capabilities by testing various supervised learning models. Specifically, Support Vector Regression and Gradient Boosting models are employed to capture non-linear patterns in the data, while a Random Forest model is explored to mitigate overfitting and handle interactions among features. Additionally, a Long Short-Term Memory (LSTM) network is tested for its suitability to handle sequential data and time-dependent forecasting.

Finally, to take advantage of similar products to forecast low-sales items, we also examine hierarchical models, which allow for a top-down approach that captures intra- and inter-product relationships.

Across all models, we utilize k-fold cross-validation to enhance robustness and reduce overfitting, with hyperparameter tuning conducted through grid search. Model performance is evaluated using the coefficient of determination (R^2), Root Mean Squared Error (RMSE), Mean Absolute Error (MAE), and Mean Absolute Percentage Error (MAPE), ensuring a thorough assessment of model accuracy.

Ultimately, we will compare model performances, assess the impact of substitution effects, and weigh the trade-offs between interpretability and predictive accuracy to identify the most suitable model for scalable retail applications.

3 The value to Society

This research holds significant potential for academic advancement and practical application in retail management. Academically, it is expected to advance knowledge on the interdependencies between perishable products, particularly the interaction between remaining shelf life, price, and consumer choice. This study will also contribute novel insights to operations research and retail analytics by developing demand forecasting models incorporating substitution effects.

From a practical perspective, the research aims to provide actionable insights for retailers, enabling them to refine demand forecasting practices, optimize stock levels, and minimize lost sales and stockouts. These improvements are expected to have significant downstream benefits for consumers, who will experience higher service levels and better product availability, resulting in a more satisfying shopping experience.

In the broader societal context, reducing perishable waste due to more accurate forecasts will contribute to the overall sustainability goals, aligning with global efforts to promote resource efficiency.

Sequential decision making in the inventory management of Port wine

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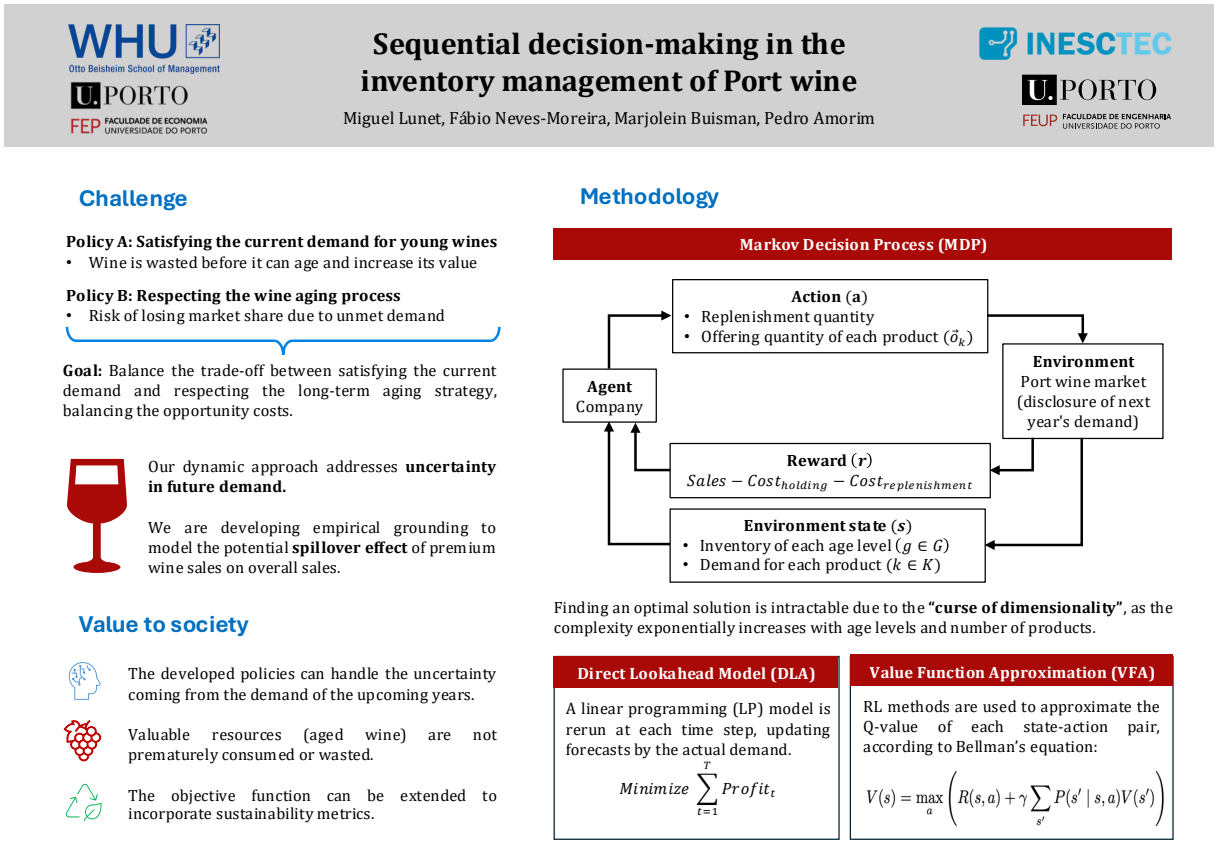

1 The Challenge

Our study examines the inventory management of Port wine, which is available in several aging levels. Like cheese, whiskey, and other fine wines, Port wine is an aging product, meaning its value tends to increase over time, with older wines commanding higher prices. While other factors such as vintage, market demand, and storage conditions also influence the wine's price, aging is one of the most significant factors.

There is demand for various categories of Port wine, including specific editions from particular years and tawnies, which are blends of wines from multiple years. For example, to meet the demand for a specific category, such as a 10-year-old tawny, a blend of both younger (less than 10 years) and older (more than 10 years) wines is utilized. Blends are common in alcoholic beverages and add complexity to the inventory management challenge.

In this market, failing to meet demand may have a detrimental effect on future demand, as customers may change to the competitors. On the other hand, sales of high-quality premium products can drive up demand through a spillover effect. While it might seem advantageous to fulfill current demand, doing so often necessitates using mid-aged wines. Once these wines are utilized, they cease to age, potentially limiting the ability to satisfy demand for older wines in the future. As a result, fewer premium wines are sold, missing out on the sales of older and more expensive wine and making it challenging to balance supply and demand effectively.

At the beginning of each year, two critical decisions are made to ensure effective inventory management. First, the replenishment quantity of 0 years old wine is determined, as this purchase represents the raw stock that will be aged for future demand. Second, the allocation of current inventory is planned by deciding how much of each product's demand to fulfill. This decision must carefully balance immediate market needs with the long-term aging strategy, as the wine sold today is no longer available to age and increase in value. For each decision, both the immediate and future values must be considered, reflecting opportunity.

2 The Methodology

This inventory management problem is modeled as a Markov Decision Process (MDP) to account for the uncertainty associated with the arrival of new information, particularly regarding product demand in the coming years.

The state space consists of the inventory of each age level and the demand for each product for the year. The action space is twofold, encompassing the replenishment quantity of new wine (0 years old) as well as the offer quantity of each product, which is restricted by the inventory and demand levels. The transition between states is the result of the update of inventory levels, as well as the disclosure of the demand for the new year. The reward is given by sales revenue, discounted by holding and replenishment costs.

An empirical grounding was conducted to quantify the spillover effect regarding port wine sales ranging between 2013 and 2023, for several brands and markets.

The interplay between immediate sales and long-term brand positioning poses a complex decision-making challenge, where the choice to hold inventory or sell it to meet current demand is not straightforward. The only possibility to purchase wine is when it is 0 years old ("vindima" stage), further emphasizing the importance of long-term planning. Stock outs of a given age level cannot be tackled by purchasing that age level directly, but rather by replenishing with a long-term approach and letting it age, even if it means leaving demand unmet.

Computing the value of each state using the Bellman equation is computationally intractable due to the extensive range of age levels and the broad spectrum of stock levels. To address this challenge, Deterministic Lookahead (DLA) and Value Function Approximation (VFA) approaches were investigated, offering two distinct methods to effectively balance short and long-term rewards.

The DLA solves a deterministic optimization problem over the entire time horizon, using a combination of real information (current inventory and demand levels) and predicted information (future demand levels). This optimization is rerun after each time step as new information becomes available. While this policy is not guaranteed to be optimal, it often serves as a good approximation, similar to the strategy used in navigation systems when recalculating the best route for each moment.

VFA seeks to determine the value of each state-action pair (Q-value) in terms of the final reward. This approach considers not only the immediate reward but also the impact on future rewards. Reinforcement Learning (RL) methods are employed to get a realistic approximation of the Q-values.

This work opens up several avenues for future research. One potential extension is to incorporate replenishment across multiple age levels, allowing for the possibility of meeting demand more quickly by acquiring inventory at a more advanced aging stage, even if it comes at a higher immediate cost. While this approach could reduce the emphasis on long-term planning, since older wines can be restocked more

rapidly, it would offer greater flexibility in managing current demand.

In future analyses, it may be beneficial to incorporate pricing decisions. By integrating pricing into the model, it could be used strategically to influence demand and better align purchasing and offering actions, ultimately enhancing overall profitability. The pricing decision would have the impact of reducing the uncertainty of upcoming demand, as it could be influenced by the price of the product.

3 The value to Society

This study contributes to sustainable consumption and production patterns, aligning with the United Nations' Sustainable Development Goal (SDG) 12. By optimizing the inventory management of Port wine, the model can help reduce waste and overproduction, key tenets of responsible production. Efficient inventory management ensures that valuable commodities, like aged wine, are not prematurely consumed or wasted, ultimately leading to a more sustainable use of natural resources. Long-term planning and strategic allocation of wine in various stages of aging demonstrate a balance between meeting immediate demand and preserving future value, reflecting the broader sustainability goals of the agriculture and manufacturing industries where the focus is on resource efficiency and long-term thinking.

Future extensions of this model could incorporate objective functions that prioritize sustainability metrics, such as improving the socioeconomic conditions of local wine producers. By integrating sustainability factors alongside profitability, the inventory management system could address issues like fair trade, organic farming, and the responsible use of natural resources. This broader approach aligns with SDG 8 on decent work and economic growth, as well as SDG 15 on life on land, by promoting sustainable agricultural practices while ensuring economic benefits for local communities.

Finally, effective management of Port wine stock directly benefits company managers handling this commodity, ensuring that the wine retains its value over time. By balancing the trade-off between unmet demand and allowing wine to age, this approach protects the long-term value of the product while supporting sustainable business operations.

Selection of Dispatching Rules over time in Dynamic Job Shops

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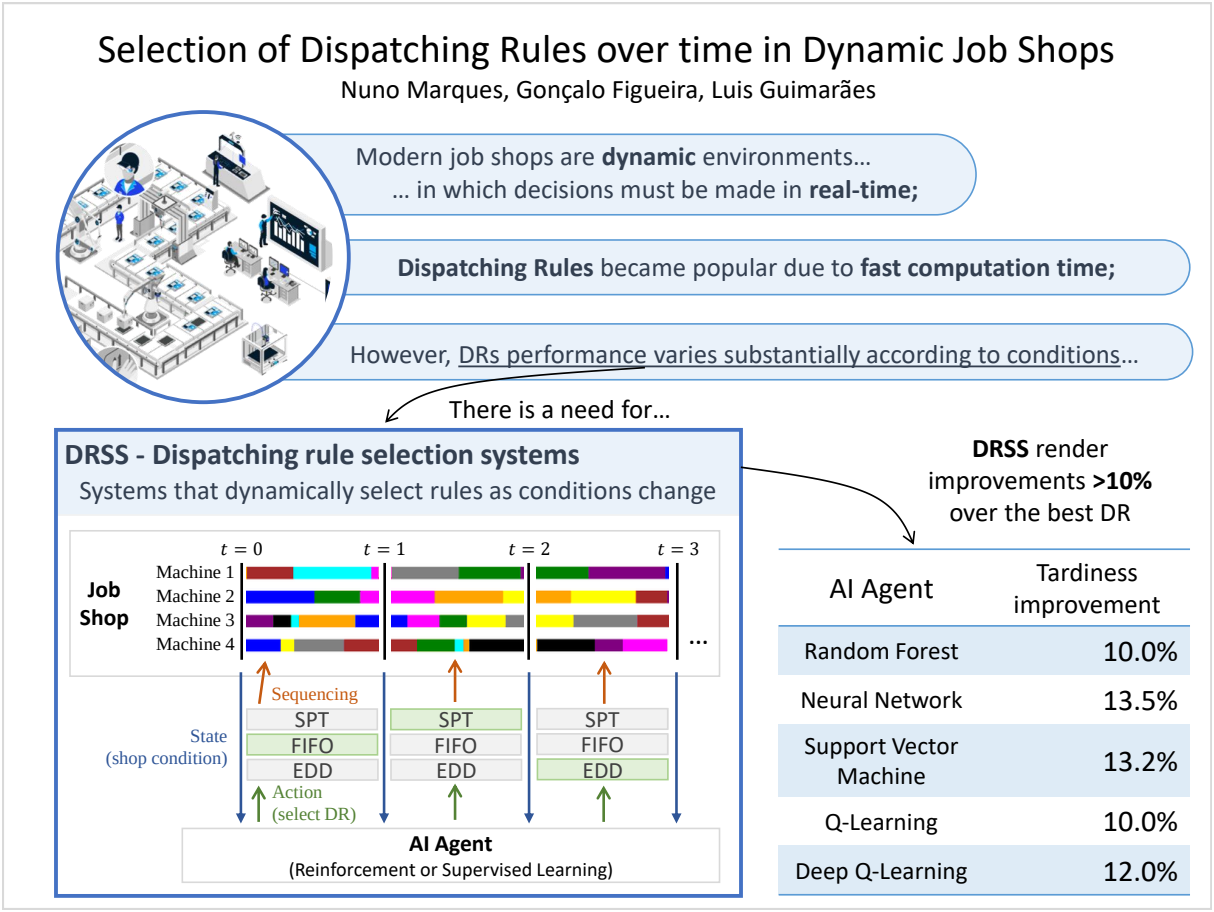
*INESC TEC and Faculty of Engineering, University of Porto



1 The Challenge

Recently, managers started introducing new technologies in factories to improve productivity. Such technologies include Internet-of-Things, Artificial Intelligence (AI), cloud, and 5G. This revolution became known as Industry 4.0 and it is a significant paradigm shift in manufacturing, as complex products can now be processed faster. Moreover, these new technologies are necessary to cope with frequent disruptions, such as unexpected job arrivals, breakdowns, and defects. These disruptions require a prompt reaction, ideally in real time.

In this work, we focus on the task of scheduling operations in dynamic job shops, which we aim to improve by using AI. Many real-world applications in the steel, semi-conductor and printing industries are modelled as job shops. In this problem, n jobs arrive over time to be processed in a pool of m machines. Information about jobs is only known upon arrival. Each job is composed by several operations that must be processed is a given sequence. The goal is to optimise a criterion such as makespan (i.e. the time

taken to process all jobs), flowtime (i.e. the time jobs spend at the shop) or, as in our case, tardiness (i.e. time jobs take to be processed beyond their due date).

Scheduling in dynamic job shops is commonly tackled relying on elementary dispatching rules (DRs), such as SPT (shortest processing time) or FIFO (first in, first out). These rules became popular because they are easy to understand and implement. Moreover, DRs are preferred to exact and meta-heuristic approaches as the former can be run in real time, unlike the latter.

However, so far, no universal DR has been found, i.e., each DR has its preferential operating conditions. Unfortunately, modern job shops are highly dynamic environments where a DR may quickly become unsuitable. Therefore, the goal of this work is to propose DR selection systems (DRSSs), i.e., systems that select DRs dynamically over time in job shops, according to their changing conditions.

2 The Methodology

The four main components of a DRSS are the state, agent, action, and environment, as depicted by Figure 1.

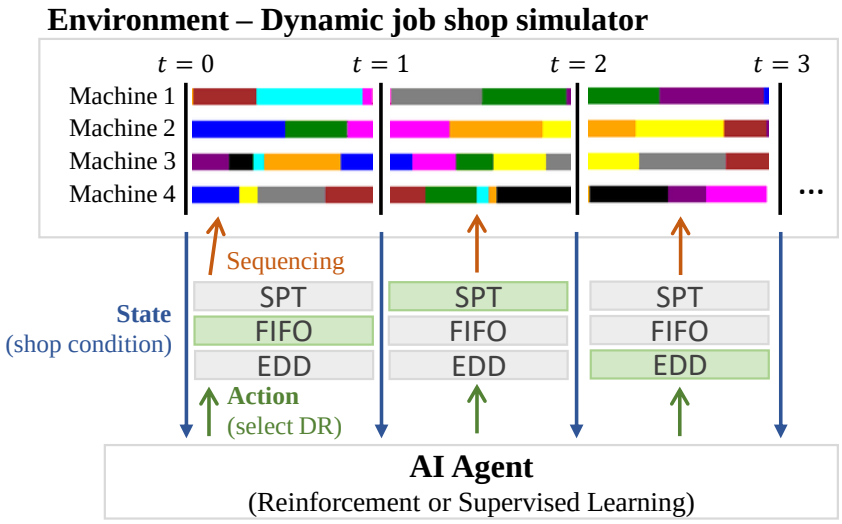


Figure 1: DRSS overview. In the beginning of each period t, the agent will observe the state $\vec{s}$ of the job shop. According to the state, a DR is chosen to become active for the current period and until a new DR select moment occurs in *t+1*.

The state is the set of variables that describes the condition of the job shop. It has been found that utilisation (i.e., the amount of work in the shop) and due date allowance (i.e., the amount of time until the due date of jobs) are the two main dimensions that affect DR performance. Over the years, several variables have been proposed for each dimension but they are highly correlated. Consequently, the superfluous variables can be removed and state sets as little as two variables (one for each dimension) were proposed.

The action is the selection of a DR, which can be chosen from a set of available DRs – the action set. Over time, researchers tried to improve the performance and robustness of DRs by including look-ahead terminals (e.g., the next processing time), by including weights between the utilisation and due date allowance-related terminals, and by generating DRs resorting to AI algorithms such as genetic programming. Thus, we tested the performance of eighty DRs from the literature to find the best ones. Three rules were selected. Each DR rendered excellent performance in different job shop conditions.

The agent is the model responsible for selecting the DR as conditions change. In the literature, two types of agent emerged: one type selects the rule at fixed periods, thus can be called periodic rule selection agent (PRS); the second type selects the rule every time a dispatching rule is used, thus can be called

real-time rule selection agent (RTRS). In this work, PRS and RTRS agents were explored to find the advantages and disadvantages of each approach.

PRS is commonly tackled with supervised learning (SL). In this work, we trained random forests, neural networks, and support vector machines for both classification and regression. The datasets to train the SL models were generated resorting to the multipass simulation technique, which evaluates the behaviour of each DR in short scheduling periods. So, for classification, each row of the dataset consists of the state at the beginning of the period and the DR with the best performance tardiness-wise. For regression, each row of the dataset includes the state at the beginning of the period and the increase in tardiness of each DR (measured in relative terms). In classification, a single model is necessary to map states to DRs, whereas in regression a model must be trained for each DR.

Our RTRS agents were trained by reinforcement learning (RL), which does not require datasets to learn. RL models learn by interacting with the environment instead, which, in our case, is a dynamic job shop simulator implemented in Java. At each decision taken by the RTRS agent, a reward is received according to the goodness of the action. As the agent interacts with the environment, it will learn which decisions lead to more rewards for each state of the shop.

During tests, it was found that some jobs would stay in the job shop abnormally long. Consequently, a fifth component was added to the DRSS, the flusher. Every time a DR is used, the flusher assesses if there are jobs that got stuck in the job shop, i.e., that are in the system for more than x units of time. If such occurs, the job chosen by the DR is disregarded and the stuck job is scheduled instead.

3 The value to Society

After extensive tests, in which the proposed models were challenged with various utilisation and due date allowance conditions, both PRS and RTRS rendered an improvement of 10% compared to DRs. Those improvements can be quite significant in real-world applications. Among all algorithms, SVMs stood out due to their robust behaviour and consequently should be preferred for implementation.

All in all, with these new systems, managers can optimise shop floor operations, thus producing more complex products in shorter periods. Customers can also benefit with the increase in productivity, as products may become cheaper. Moreover, DRSSs can improve working conditions, as employees can count on the support of intelligent systems to streamline and enhance their decision-making process. Finally, optimised production leads to less energy and raw material consumption, thus reducing the toll on the environment. Therefore, implementing DRSSs is aligned with the United Nations' Sustainable Development Goals 9 and 12, which are related to sustainable industrialisation and production.

It must be recognised that despite several benefits, the implementation of DRSS comes with challenges. To start, DRSSs require real-time monitoring of resources and work in progress. Moreover, job transport around the shop should be done autonomously. Therefore, DRSSs are suitable for smart industrial settings. However, for settings that are not ready for Industry 4.0, acquiring or updating existing industrial equipment and training or hiring new staff may be financially prohibitive. Finally, DRSSs are a highly flexible tool and, thus, can be used in many industries, regardless of the scale of the problem. However, it may be necessary some adaptation when implemented in real-life applications due to different shop sizes, job types and constraints.

Machine Learning Approach applied to Logistics Ergonomics: Challenges and Opportunities

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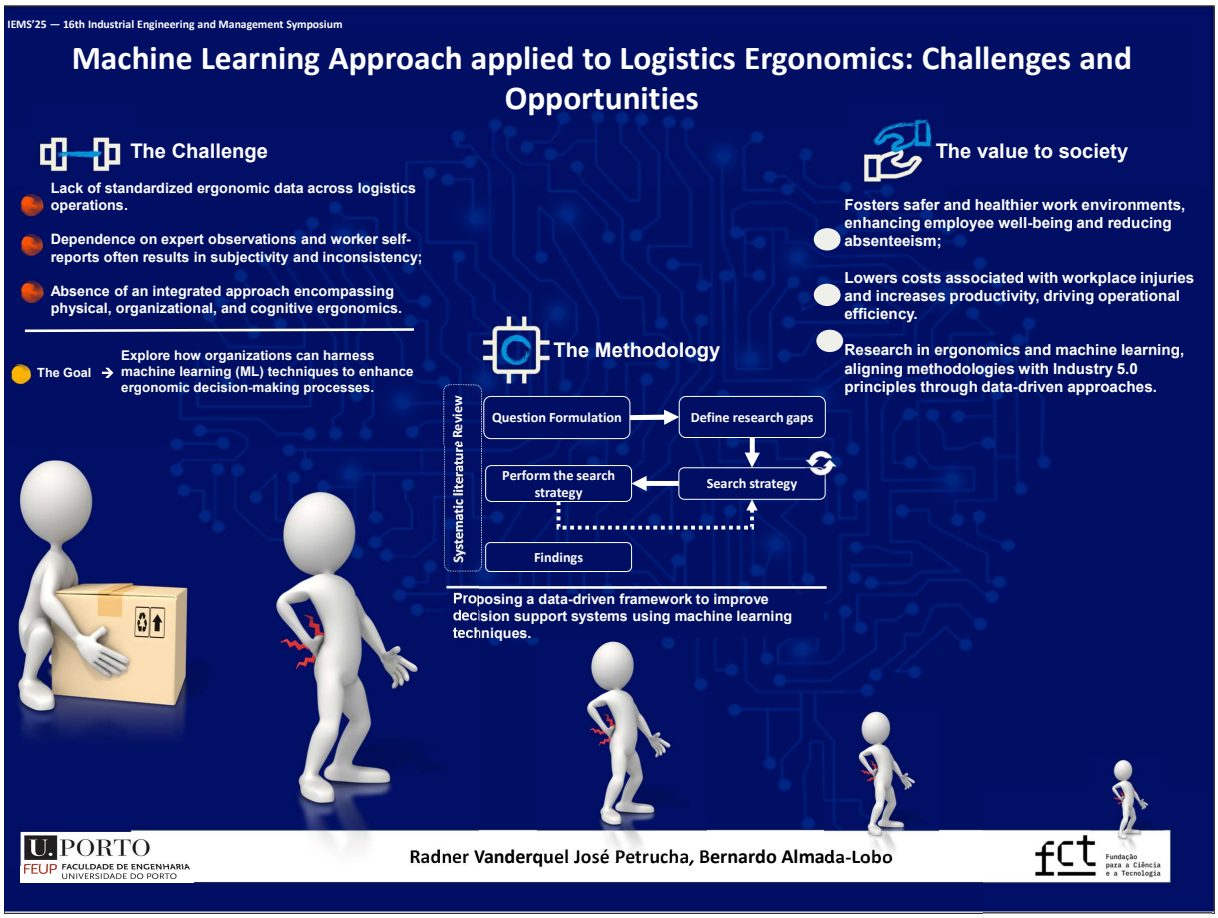

1 The Challenge

The logistics sector is intrinsically tied to physical labor, which inherently exposes workers to various occupational hazards, including injuries, fatigue, and musculoskeletal disorders. Traditional ergonomic assessments, primarily depend on expert observations and self-reports from workers and therefore, are frequently marred by subjectivity and inconsistencies The core challenge lies in transitioning from this manual evaluation system to a data-driven approach that can not only predict ergonomic risks but also facilitate continuous improvements.

Moreover, the lack of standardization in ergonomic data across different logistics operations presents a significant hurdle, as variability in tasks, worker postures, and environmental conditions complicates the development of generalized models applicable across industries. This work aims to address these gaps by leveraging machine learning (ML) to create adaptable, data-driven frameworks that integrate diverse

ergonomic metrics into decision-making processes. For instance, ML models can analyze data from different sources and predict risks like fatigue or repetitive strain and suggest interventions such as task reallocation or rest breaks to mitigate these risks. Additionally, skepticism among workers and management, driven by privacy concerns and fears of diminished autonomy, often impedes the adoption of such models. By demonstrating practical applications – such as optimizing task allocation to reduce physical strain – this research bridges the gap between theoretical advancements and practical implementations, offering solutions that enhance worker well-being while maintaining operational efficiency.

This work aims to explore how organizations can harness machine learning (ML) techniques to enhance ergonomic decision-making processes in logistics operations. By gaining a deeper understanding of ML's analytical capabilities, future research in logistics can adopt personalized information systems that proactively respond to the dynamic and stochastic nature of logistics operations. Integrating ergonomic principles into these models holds the potential to significantly improve operational efficiency while mitigating the risks associated with occupational diseases.

2 The Methodology

To address the challenge a systematic literature review (SLR) aforementioned was conducted based on proven guidelines by (Denyer and David Tranfield, 2009).A five-step methodology for researching the application of machine learning to ergonomics and logistics was pursued as follows: Step 1 defines the research question based on scoping studies in ergonomics, machine learning, and logistics. Step 2 reviews the literature to identify gaps and build a theoretical background. Step 3 develops a search strategy, selection criteria, and data extraction forms. Step 4 performs the search, analyzes results, and extracts relevant data. Step 5 presents findings and discusses insights from the analysis. For this purpose, the articles obtained using Scopus databases were limited by the last 10 years, by only academic scientific discipline, and type of document. Finally, all three keyword groupings are combined into one search string to find the multidisciplinary type of publications searched : TITLE-ABS-KEY[Ergonomic* (Synonyms) OR Domains] AND TITLE-ABS-KEY[ML (Synonyms OR Techniques] AND TITLE-ABS-KEY[Logistics (Application fields)]

Initially, 210 papers were identified. Following a meticulous review of abstracts and titles, and those that did not align with the research scope (ML, Ergonomics and Logistics) were excluded. The remaining articles were organized into a matrix to help categorizing them based on different thematic criteria. The quality of each study was evaluated, and after eliminating 60 duplicates, 150 papers were retained. These were then grouped into three priority categories based on their relevance to the research question, and finally, 112 articles were selected for detailed analysis. These represent the most significant contributions to understanding machine learning's application in ergonomics within logistics settings.

For data analysis, the articles were categorized into three groups: those addressing ergonomic domains, those applying ML to support ergonomic decision-making in logistics, and those highlighting ML benefits such as injury reduction, fatigue minimization, and posture optimization. A total of 68 articles on ML in complex systems were included in the final analysis.

Simultaneously to the the development of the literature review, brainstorming sessions with Ergonomics and Safety experts from a Portuguese company in the retail sector were held. This allowed an early understanding of the theme of the field of Ergonomics in the industry, its domains and applications, a vision of the impact of decision-making in the operational process, and a perception of the impacts and limitations of current analytical methodologies in the industry.

The results highlight significant gaps in applying ML to ergonomics in logistics. While ML is increasingly used for automation and optimization, few studies holistically address ergonomic challenges. Most approaches focus on isolated aspects, such as task allocation or order picking, often overlooking ergonomic criteria and worker well-being. This reflects the complexity of accounting for diverse physical, cognitive, and operational factors while ensuring adaptability to dynamic environments.Techniques like convolutional neural networks (CNNs) for posture recognition, reinforcement learning for task allocation, and genetic algorithms for workflow optimization show potential but remain underutilized. Progress in digital twin modeling and multi-objective optimization is also limited in logistics. Research continues prioritizing productivity over critical worker health metrics, such as posture, fatigue, and stress. A key gap lies in improving worker-robot collaboration to balance mental and physical workloads, especially with the rise of collaborative robots. Integrated ML frameworks combining diverse ergonomic data are essential to

enhance worker safety and operational efficiency.

The next step of this research intends to develop, a data-driven approach framework to enhance decision support systems by integrating ergonomic metrics to ensure a comprehensive ergonomic assessment. This approach aims to leverage advanced data analytics and predictive modeling to identify and mitigate risks, such as fatigue and mental overload before they escalate, particularly in diverse operator contexts. By harnessing data from various sources, we will then develop algorithms to detect patterns and anomalies, enabling timely interventions that improve worker safety and overall productivity. This proactive strategy facilitates a more resilient manufacturing ecosystem, ultimately leading to optimized operational efficiency and worker well-being

3 The value to Society

The adoption of Machine Learning (ML) in ergonomics offers significant societal benefits by creating safer and healthier work environments. This leads to reduced workplace injuries, lower absenteeism, and increased productivity. Economically, decreased injury-related costs translate to gains for businesses, while improved conditions enhance worker satisfaction and retention.

In the context of Industry 5.0, which emphasizes human-centric technology, ML-driven ergonomics places worker well-being at the forefront of industrial innovation. This shift supports sustainable development by balancing operational efficiency with human health. ML's ability to provide real-time insights, predictive risk assessments, and dynamic task adjustments using diverse data from wearables and sensors enables proactive interventions, such as mitigating fatigue or optimizing workloads, beyond what traditional approaches can achieve.

ML can optimize worker well-being by addressing physical (fatigue, repetitive motions), organizational (workload, task flow), and cognitive (mental stress, information overload) aspects of ergonomics. By transcending traditional injury prevention, ML fosters a more balanced, health-focused work environment, aligning with Industry 5.0's human-centered principles.

In the long term, this approach could revolutionize workplace health and safety management. By providing data-driven insights, ML supports effective and personalized occupational health policies, enhancing worker well-being while driving sustainability in logistics operations.

Structuring Complex Operations Environments

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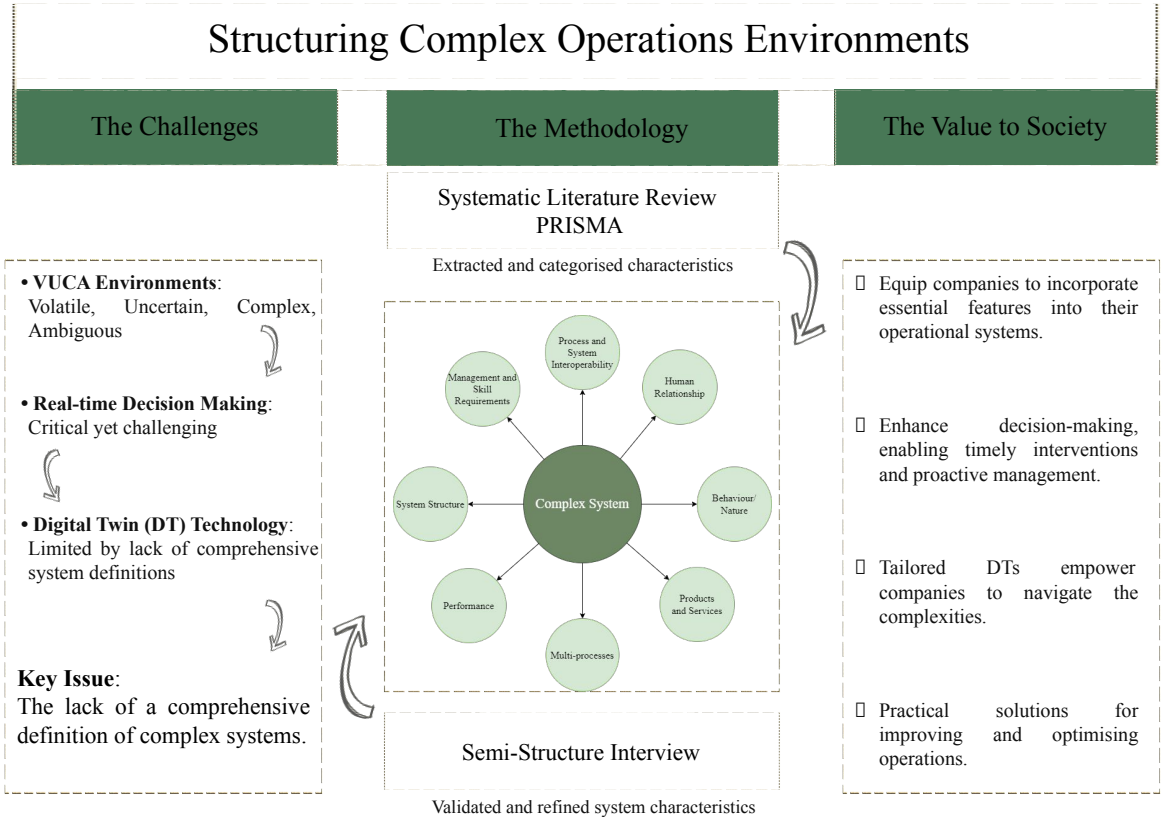

1 The Challenge

In today's rapidly evolving, volatile, uncertain, complex, and ambiguous (VUCA) environments, Complex Operations Environments (COEs) have become prevalent across sectors such as manufacturing, logistics, and production. These environments involve numerous interacting elements, unpredictable dynamics, and intricate subsystem relationships, all of which complicate decision-making processes. A significant challenge is making real-time, informed decisions amidst the inherent complexity and unpredictability.

Digital Twin (DT) technology, which offers real-time digital replicas of physical systems, provides the potential for managing these complexities. Continuously updated with data from the physical system, DTs enable monitoring, control, and optimisation across various stages of a system's lifecycle. However, the successful application of DTs is hindered by the absence of a comprehensive definition of what constitutes a complex system.

In alignment with our research, a precise definition of complex systems, particularly in operational environments, continues to represent a substantial gap in the existing literature. Although previous research has explored the characteristics of complex systems, these definitions often fall short of fully capturing

the dynamic, interconnected, and evolving nature of COEs. This gap limits the effectiveness of DT technology to improve decision-making processes.

Our research addresses this gap by developing a comprehensive, hierarchical conceptualisation of COEs that encapsulates the intricate interdependencies between processes, systems, human interactions, and technologies. While not offering a definitive COE definition, this work offers a structured foundation for further exploration and definition in future studies. This conceptual framework forms the basis for designing DT applications that can adapt to and accurately reflect the unique complexities of COEs, especially in sectors such as manufacturing and logistics. By offering a structured, systematic approach to characterising and modelling these environments, our work paves the way for more efficient operations, reduced risks, and enhanced decision-making capabilities.

The rapid pace of technological advancements and the increasing interconnectivity among systems add layers of complexity, making the task of defining COE characteristics even more urgent. Tailored DT solutions that capture the dynamic behaviours and interdependencies of these environments are vital for enhancing operational efficiency and decision-making. By offering a systematic approach to characterising these environments, this study lays the groundwork for future advancements, aims to advance theoretical understanding and provides scalable, practical solutions that enhance resilience and adaptability in today's fast-paced, interconnected operational landscapes.

2 The Methodology

To address the challenge of defining COE characteristics, this study employed a dual-phase methodological approach:

1. **Systematic Literature Review:** In the first phase, a Systematic Literature Review was conducted following the PRISMA methodology. PRISMA will ensure methodological rigour and reliability by minimizing bias and enhancing the validity of our findings. This review spanned multiple academic databases, extracting a wide range of characteristics that define complex systems. These characteristics were systematically organised and synthesised into a hierarchical conceptualisation consisting of eight primary categories: Process and System Interoperability, Human Relationship, Behaviour and Nature, Products and Services, Multi-processes, Performance, System Structure, and Management and Skill Requirements. This conceptualisation provides a comprehensive structure for understanding COE complexities, offering a clearer path for the integration of DT technology.
2. **Semi-Structured Interviews:** In the second phase, semi-structured interviews were conducted with industry experts from three distinct business units within AMORIM, a company deeply embedded within a COE. These interviews provided practical insights that enriched, refined and validated the theoretical conceptualisation from the literature review, ensuring its applicability in real-world operations. The interview data were coded using Grounded Theory, allowing for the systematic identification of key themes and patterns aligned with the conceptual model. This process ensured that the conceptualisation reflects both theoretical and practical perspectives, enhancing its robustness and applicability.

By incorporating insights from distinct operational contexts within a single organisation, the study captures a range of empirical aspects without confining the conceptual framework to a specific industry or system. This process strengthened the conceptualisation, making it a reliable foundation for designing DT applications tailored to COE needs. The hierarchical model, with its eight main groups, presents a holistic view of complex systems, integrating key elements essential for system optimisation.

3 The value to Society

The outcomes of this research offer significant contributions to both academic and industrial sectors. By providing a structured and validated framework for understanding the characteristics of COEs, this study equips companies with the knowledge needed to incorporate essential features into their operational systems, addressing contemporary challenges more effectively.

From an industrial perspective, this research enhances decision-making capabilities within COEs, enabling timely interventions and proactive management. These advancements contribute to greater operational

efficiency, reduced risks, and cost savings, particularly in sectors where real-time monitoring and decision-making are critical to maintaining competitiveness.

Moreover, developing tailored Digital Twins based on our conceptual model will empower companies better to navigate the complexities and interdependencies inherent in COEs. This fosters resilience, adaptability, and long-term sustainability, which are increasingly vital in today's interconnected and rapidly evolving global market.

By addressing the complexities of COEs, this research advances theoretical understanding and provides actionable, practical solutions for improving and optimising operations. Ultimately, the research contributes to creating more efficient and sustainable operational environments, offering long-term benefits to society by enhancing industrial productivity and sustainability.

From Stigma to Style: Unlocking the Potential of Second-Hand Services

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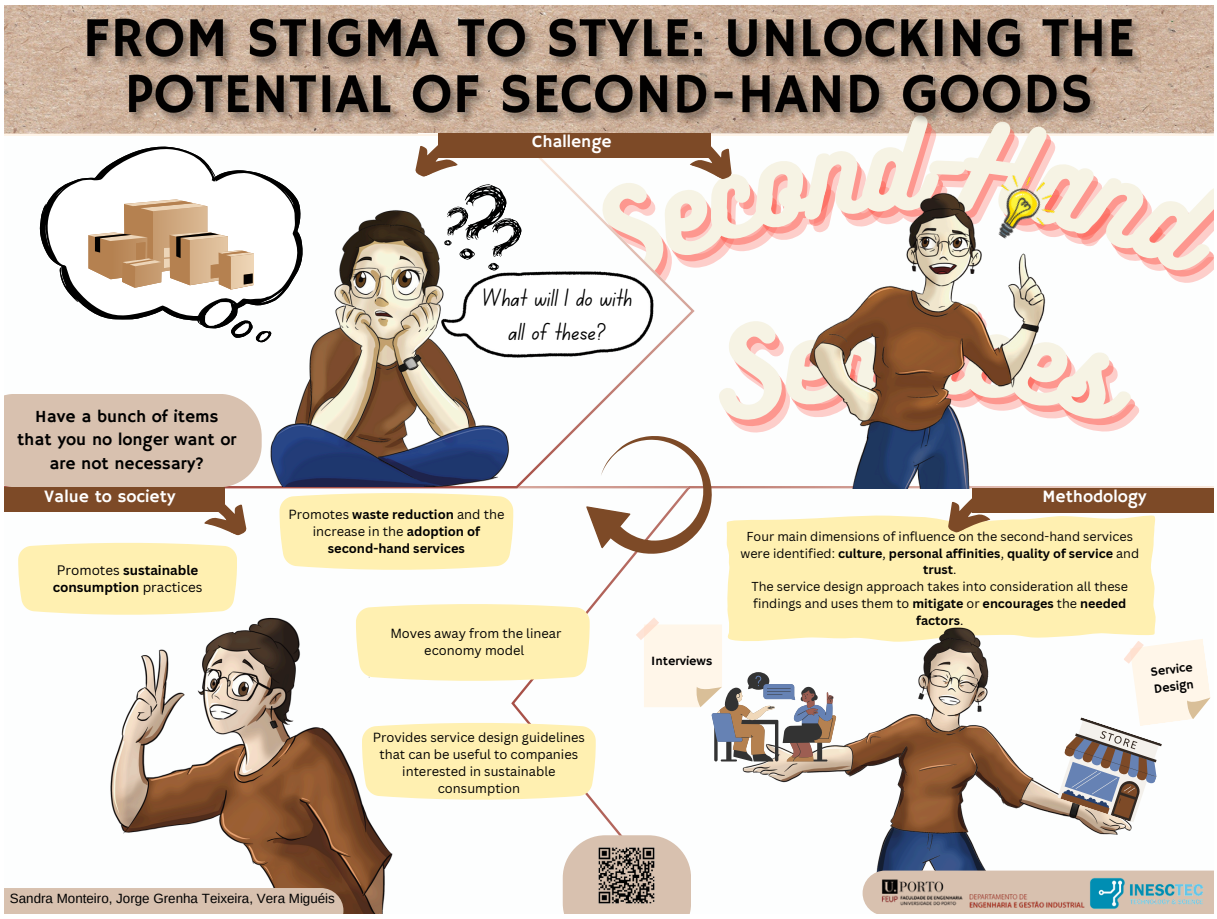

1 The Challenge

As the literature emphasizes, environmental issues are increasingly more worrisome due to climate change, excessive waste, pollution, and water scarcity. Among the solutions, circular economy mitigates these concerns and aims to break linear production through a 3R (reduce, recover, recycle) approach. Reducing the production and increasing the life-cycle of goods can be achieved through the second-hand sale of these items through dedicated services, such as physical stores and online platforms. Hence, this study aims to identify and analyze the barriers and drivers that influence customer interaction with second-hand services. By examining these dynamics, the study seeks not only to clarify what deters or motivates customers but also to develop a tailored service design for a resale home goods store that addresses these insights.

2 The Methodology

The study integrates qualitative interviews and a service design approach to examine in-depth the barriers and drivers influencing the customer interaction with the second-hand services.

The qualitative interviews are conducted to gain insights regarding the barriers and drivers to interact with these services - from an "way in" (purchase, receiving donation, etc.) and "way out" (donating, selling, recycling, etc.) of items - as well as regarding the why (justifications) and what (type of items). For data collection, 43 individuals, both female and male, mainly from the Porto district, were interviewed. Following theoretical sampling procedures, interviewees come from all age groups (greater than 18 years old), ranging from education levels of 6th grade to Ph.D. degrees, and from distinct professional areas. The average duration of the interviews stands at 26 minutes. The interviews were recorded and are being literally transcribed and analyzed with the support of NVivo software (version 14). Four dimensions were identified so far: culture, personal affinities, quality of service and trust. Inside each dimension, several factors have been unveiled, such as education, social status, and cultural prejudices inside the culture dimension; price, sustainability, and economic return inside the personal affinities dimension; appearance, communication, and usability inside the quality of service dimension; and fraud potential, warranty and security, and transparency inside the trust dimension.

Finally, the study uses a service design approach to translate these findings into a new second-hand service. Service design is a customer-centric approach that supports, through several methods and models, the design of a service that mitigates barriers and enhances drivers identified in qualitative interviews. By taking this approach, the study develops an end-to-end customer experience, attuned to customer insights, and increasing the probability of the second-hand service adoption.

3 The value to Society

Given the need to break a linear economy mindset, circular economy, and, specifically, the reuse of items, has become crucial for society. As such, this study contributes to this imperative by understanding the dimensions that frame how customers perceive and interact with second-hand services, and by designing a second-hand service. Thus, this study also promotes sustainable consumption practices, reduction of waste, and increase in the adoption of these services. Furthermore, by identifying the barriers and drivers, that deter or encourage customers to interact with second-hand services, the study contributes to a broader shift towards circular economy, moving away from the traditional "make-use-waste" model. On the other hand, the study also provides practical insights for companies interested in fostering sustainable consumption. By understanding customer motivations and concerns about second-hand services, the study acknowledges the dimensions of influence (culture, personal affinities, quality of service, and trust), and provides service design guidelines that address the relevant improvement and mitigation areas.

Sustainable mobility and transportation mode choices: Data-driven insights from the Asprela University Campus

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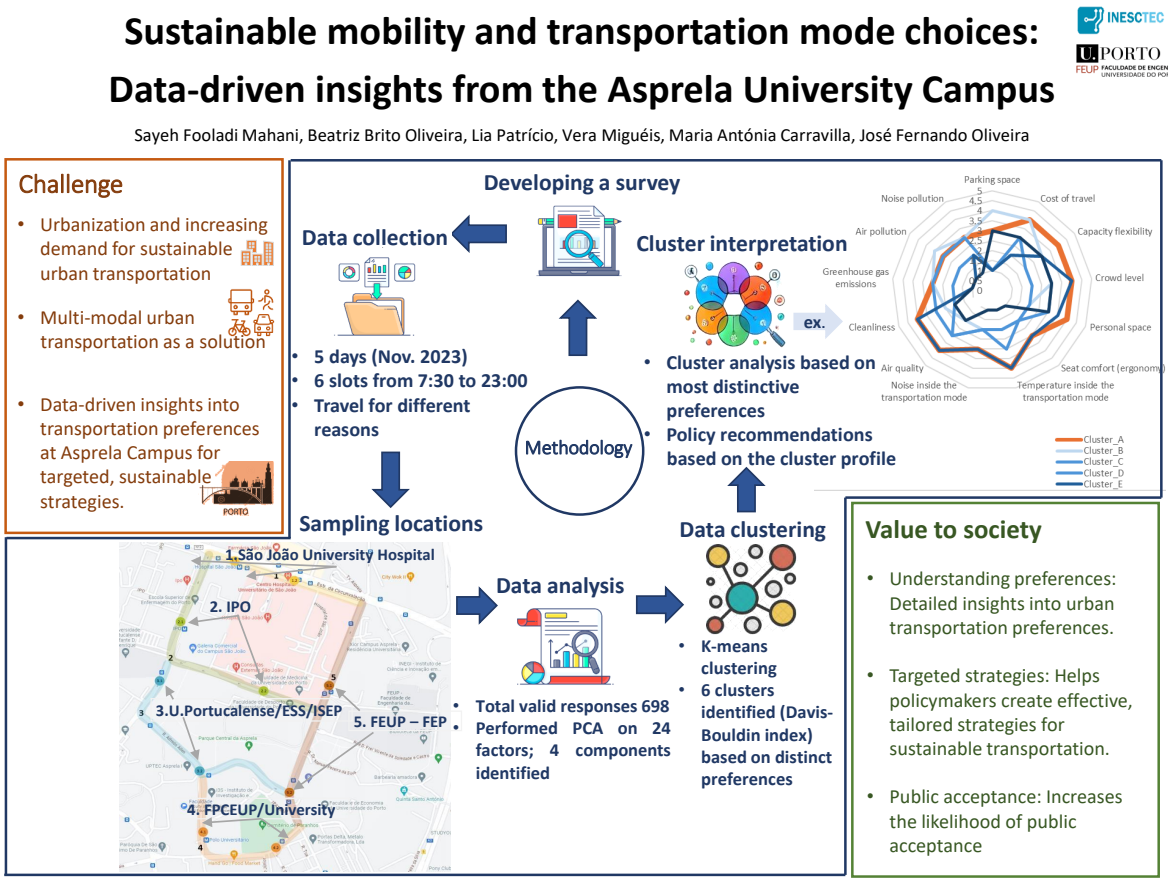

1 The Challenge

Urban growth increases the need for efficient and sustainable transportation. Multi-modal systems, which integrate different modes, can reduce traffic, emissions, and improve urban living, but their success relies on public acceptance. This study identifies the factors influencing transportation mode choices and examines how users prioritize them. The case focuses on Porto's Asprela Campus, a 1.5-2 km^2 urban area with diverse facilities, including educational institutions, hospitals, and commercial zones, which generate varied travel activities. Asprela serves as a representative model for mobility studies in similar urban areas.

2 The Methodology

Our methodology consists of three steps: survey design, data collection, and data analysis. This approach identifies the key factors influencing urban transportation mode choices and how users prioritize them.

2.1 Survey Design

Based on a literature review, the survey was developed to understand factors influencing transportation mode choices, with questions adapted from previous studies. The survey includes three main parts: the first part covers factors affecting transportation mode choices, using a Likert scale (1=*Not at all*, 2=*Slightly*, 3=*Moderately*, 4=*Very*, 5=*Extremely*, 6=*I don't know/I prefer not to answer*). The second part focuses on the specific mode of transportation used to reach Asprela Campus. This includes personal vehicles, buses, subways, taxis, or ride-hailing services. Additionally, it explores the trip's objective and subjective aspects, such as overall satisfaction and perceived value. The third part gathers information about the respondent's demographics, such as age, gender, education, monthly transportation expenses, and income. The survey was initially developed in English and subsequently translated into Portuguese for local application. A pilot study involving 50 participants resulted in minor adjustments prior to the final data collection.

2.2 Data Collection

The data was gathered through face-to-face interviews conducted over five consecutive working days in November, across six slots from 7:30 to 23:00. The surveys were administered in Portuguese to individuals aged 18 or older who traveled within the Asprela Campus, Porto, for various purposes such as work, study, or hospital visits. To ensure coverage, interviews were evenly distributed across five sub-zones, with randomized respondent selection.

2.3 Data Analysis

The data analysis followed a structured approach involving descriptive statistics, Principal Component Analysis (PCA), Cluster Analysis (CA), Kruskal-Wallis (KW) testing, and Dwass-Steel-Critchlow-Fligner (DSCF) testing to identify factors affecting transportation choices and how users prioritize them.

Descriptive statistics: A total of 722 people were interviewed, with 698 valid responses (96.7% response rate). The survey's first part included 24 questions on factors affecting transportation mode choices, with most respondents rating factors as moderately important. The sample was predominantly composed of younger individuals, reflecting the university-centric nature of the area, with a balanced gender distribution. Most participants had completed high school or higher education, and a significant portion reported no income, consistent with the large student population.

Principal component analysis: To reduce the dataset into manageable components PCA was used. The suitability of the PCA was confirmed with a Kaiser-Meyer-Olkin (KMO) value of 0.91, indicating strong sampling adequacy, and Bartlett's Test of Sphericity ($p < 0.001$) further validated the dataset's suitability. The optimal number of components was determined using eigenvalues and a scree plot. The scree plot indicated that four components, with eigenvalues greater than 1, explained the majority of variance in the data.

Cluster analysis: To further analyze the data, K-means clustering was applied, using the Davies-Bouldin (DB) index to determine the optimal number of clusters. The DB index identified six clusters. These clusters were based on PCA scores, revealing distinct mobility preferences among the respondents. K-means clustering was then performed, partitioning the data into six distinct clusters: Cluster A (30.80% of the respondents), Cluster B (10.88%), Cluster C (22.77%), Cluster D (13.89%), Cluster E (10.88%), and Cluster F (10.74%).

Clustering interpretation: To interpret the clusters, the KW test and the DSCF test were used to identify the significant factors distinguishing each cluster. These tests highlighted key factors differentiating the clusters. For example, Cluster A (Figure 1) (30.80% of the sample) prioritizes comfort and cost, with moderate concern for environmental factors. Socio-demographic characteristics were not used for clustering, but they provide further insights into the profiles. For instance, users in Cluster A have a

median age of 38 years (higher than the overall sample median of 24) and a median income level between €500-1000. This suggests that older, higher-income individuals in this cluster prioritize comfort and cost when choosing transportation modes. Similar analyses were conducted for the other clusters.

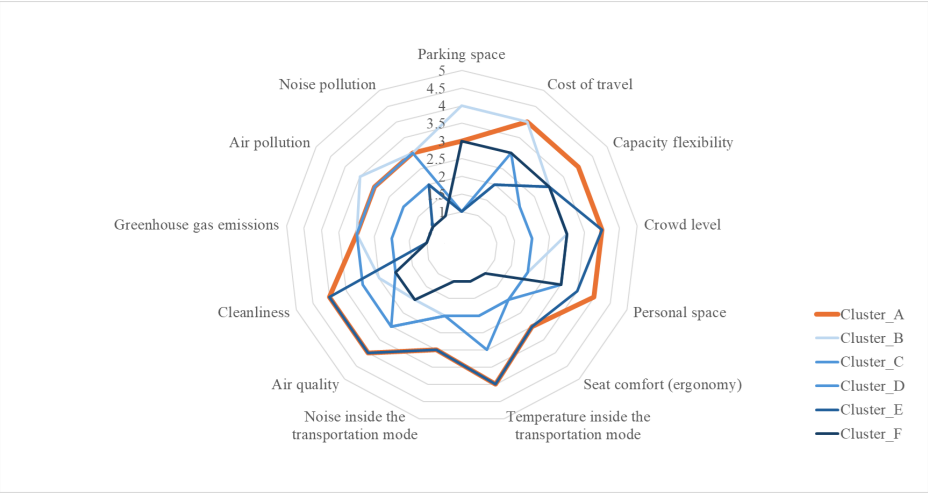

Figure 1: Visualization of the distinguishing factors in mode choice for users in Cluster A (vs. other clusters). The axes show the median values of responses from the Likert scale (1 = Not at all, 5 = Extremely), indicating how users in this cluster prioritize various factors when selecting an urban transportation mode. Each corner of the spider graph represents a factor that significantly distinguishes this cluster from others.

3 The value to Society

This study offers insights for promoting sustainable urban transportation by identifying user profiles based on transportation preferences. Policymakers can develop targeted strategies to encourage the adoption of greener modes like public transport, cycling, and walking. These strategies help reduce traffic, lower emissions, and improve air quality, aligning transportation policies with user needs. Cluster analysis enabled tailored policy suggestions. For example, Cluster A prioritizes cost and comfort, making fare discounts, subsidized public transport, or partnerships with shared mobility services ideal for this group. Mobility-as-a-Service platforms could also be beneficial. Similar approaches were proposed for other clusters, ensuring targeted interventions for sustainable urban mobility.

Fair Order Fulfillment in Online Marketplaces via Reinforcement Learning

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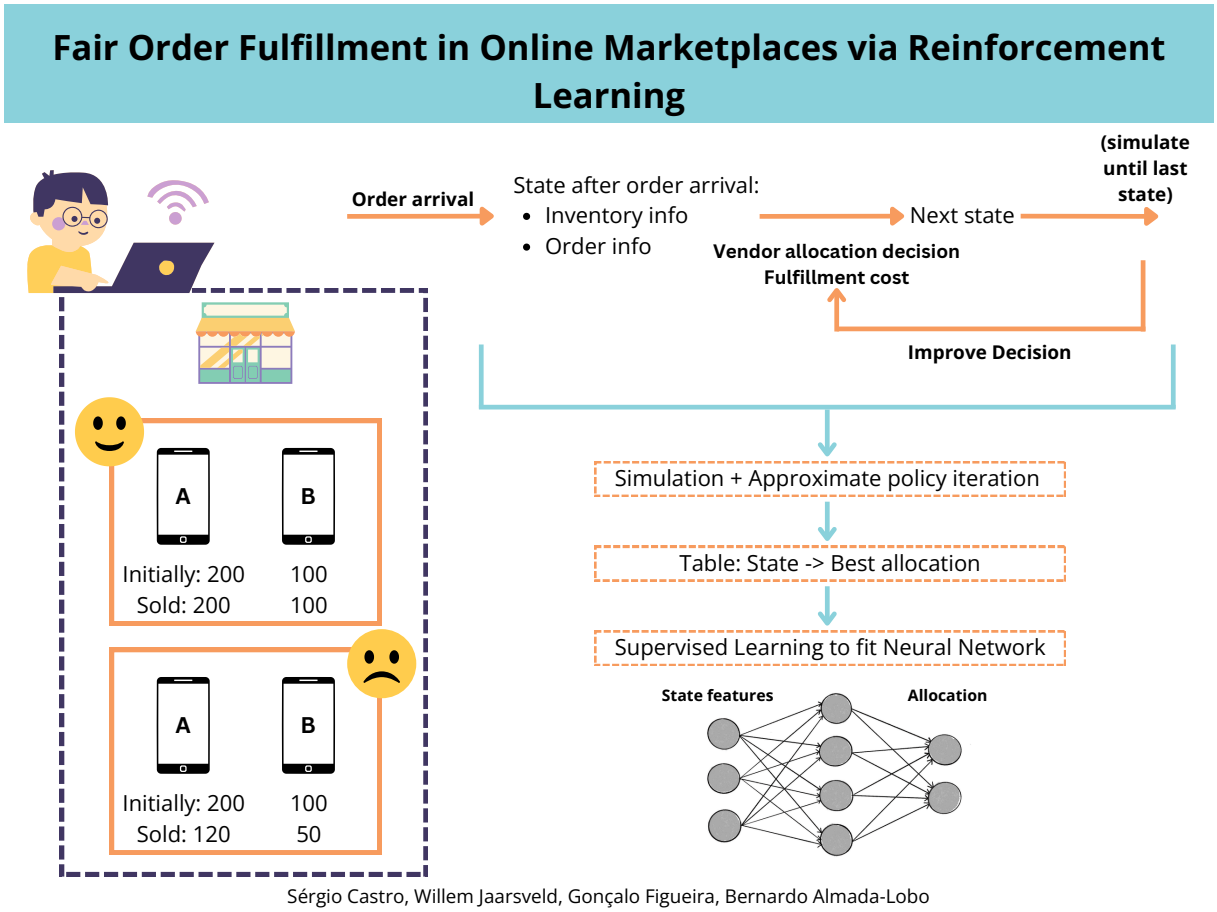

1 The Challenge

This work addresses the optimization of order allocation, a significant factor in last-mile fulfillment costs. Order allocation involves directing demand to specific fulfillment nodes, balancing immediate and future costs, which is challenging due to the need to make quick decisions under uncertainty, e.g. in demand, fulfillment costs, and stock levels. Myopic methods that allocate demand to the nearest or cheapest node are widely used but often result in sub-optimal outcomes as they ignore future demand. More sophisticated methods, including approaches combining Mathematical Programming (MP) and Dynamic Programming (DP), attempt to balance current and future costs but add complexity.

Recently, Deep Reinforcement Learning (DRL) methods, such as Proximal Policy Optimization (PPO), have shown promise in optimizing order allocation through data-driven approaches. However, comparative research on different optimization methods – like MP, DP, and DRL – is limited, and current DRL applications often address only basic problems, such as single-item order allocation. This work aims to fill these gaps by (1) directly comparing DRL approaches with myopic and other established methods and (2) addressing a more complex and realistic problem.

For (1), we implement Deep Controlled Learning (DCL), a DRL method designed for inventory control, which combines approximate policy iteration and supervised learning. DCL implements iterative efficient simulations to create datasets containing states and their estimated optimal actions, enhancing policies through iterative classification tasks. The main difference between DCL and PPO is that DCL circumvents the need for cost approximation via neural networks, directly estimating optimal actions instead. We assess DCL's performance against various myopic policies and MP-based heuristics.

For (2), we focus on multi-item order fulfillment with fairness considerations, a critical issue in online marketplaces where a single platform connects multiple vendors to buyers. When vendors sell identical items, determining their fulfillment responsibilities can lead to conflicts. Beyond typical goals like minimizing shipping costs, we emphasize the need to enhance vendor satisfaction to prevent potential withdrawal, stock reduction, or assortment limitations, which could affect the marketplace's overall appeal. We handle vendor satisfaction with the concept of fairness, namely by considering that each vendor considers a set of allocations to be fair if it sells at least a certain proportion of their inventory.

For our problem setting, we consider a selling season consisting of multiple time steps, during which multiple items are fulfilled by multiple vendors. At the start of the horizon, each vendor commits an initial amount of inventory for each item. At each time step, an order originates from one customer region. Each order is described by the subset of items that were just purchased. Up to one order arrives in each time step. We consider the variable cost of fulfilling one unit of any item from a given vendor to a given region and the fixed cost of sending a package (containing one or more items) from a given vendor to a given region.

Furthermore, we consider the number of allocations made to each vendor at the end of the horizon and the proportion of each vendor's initial inventory that the vendor expects to sell by the end of the horizon under fair conditions (fairness proportion). A penalty associated with not meeting the fairness proportion at the end of the horizon is also considered.

The problem's goal is to dynamically determine which vendors to use to fulfill the items in each order that arrives over the time horizon, to minimize the total expected cost plus the fairness penalty. Demand may be left unfulfilled. Therefore, we also consider the unit and fixed "shortage" cost of failing to fulfill demand.

2 The Methodology

We formulate the problem as a finite horizon MDP with exogenous inputs. An *event* corresponds to the arrival of a new customer order, defined by a customer region and a subset of items. An *action* corresponds to the allocation of an item in the subset to a vendor[1]. Actions are constrained by the amount of the current inventory of each vendor of each item, which must be greater than 0. The *rewards* correspond to the fixed and variable shipping costs, as well as the fairness penalty and the unfulfillment costs mentioned in the problem description. We consider two types of *states*:

- States S – occur either at the start of the horizon, before any order arrival, or immediately after completing an order allocation. It includes the information on the current inventory state and the number of time steps remaining until the end of the horizon.
- States $S+$ – occur after an order arrives or while an order is being allocated. Besides the information included in S states, S+ states also include information on the customer region, subset of items demanded and the list of vendors that have already been allocated to items of the current order.

Finally, we consider the following *transitions*: (1) S - to - $S+$ – occurs when a new order arrives, (2) $S+$ - to - $S+$ – occurs in multi-item orders when an action is taken which leads to another action, (3) $S+$ - to - S – occurs when the allocation of the entire order is completed, (4) S - to - S – occurs when no order arrives in a time period.

Our experimental setup consists in two steps. In the first step, we set the fairness penalty to 0, which effectively transforms the problem in the multi-item order fulfillment problem with the fulfillment cost minimization objective. For this problem, we introduce two types of instances, one based on the literature,

[1]Note: Although an order size may contain multiple items, each item is allocated individually. For example, for an order with 2 items, 2 different $S+$ states occur – when the order arrives, and after the first item is allocated.

using an instance generation method proposed in an established paper (*literature* instances), and another based on adapting the instance generation method to create instances that more closely mimic the real world (*real* instances). We then compare DCL with three heuristics which are constructed based on an approximate linear problem and a myopic heuristic that always allocates items to the vendor with the minimum immediate shipping cost.

In the second step, we consider the fairness penalty by assuming that each vendor expects to sell the same proportion of their inventory, such that vendors that sell bellow the average allocation proportion incur in a penalty. The same *literature* and *real* instances are considered under this setting, which allows for direct comparison between not considering and considering fairness. Under the consideration of fairness, the DCL policy is compared with a myopic heuristic that minimizes the immediate shipping cost and the expected fairness penalty.

3 The value to Society

This research contributes to the academic and business communities by (a) being the first work to compare DRL methods with other established methods based on MP in the online order allocation problem, highlighting the advantages and limitations of DRL, and (b) introducing the concept of fairness, a pivotal aspect of order allocation in online marketplaces with competing vendors, which sheds light into how marketplaces can improve their operational allocation decisions to optimize long-term objectives, including cost minimization and partner satisfaction.

We also note that the concept of fairness can be extended to other supply chain agents, even outside online marketplaces – e.g., suppliers, carriers, and other third-party logistic partners – opening up future research opportunities.

A Multi-Objective Approach to Last-Mile Delivery with Crowdshipping

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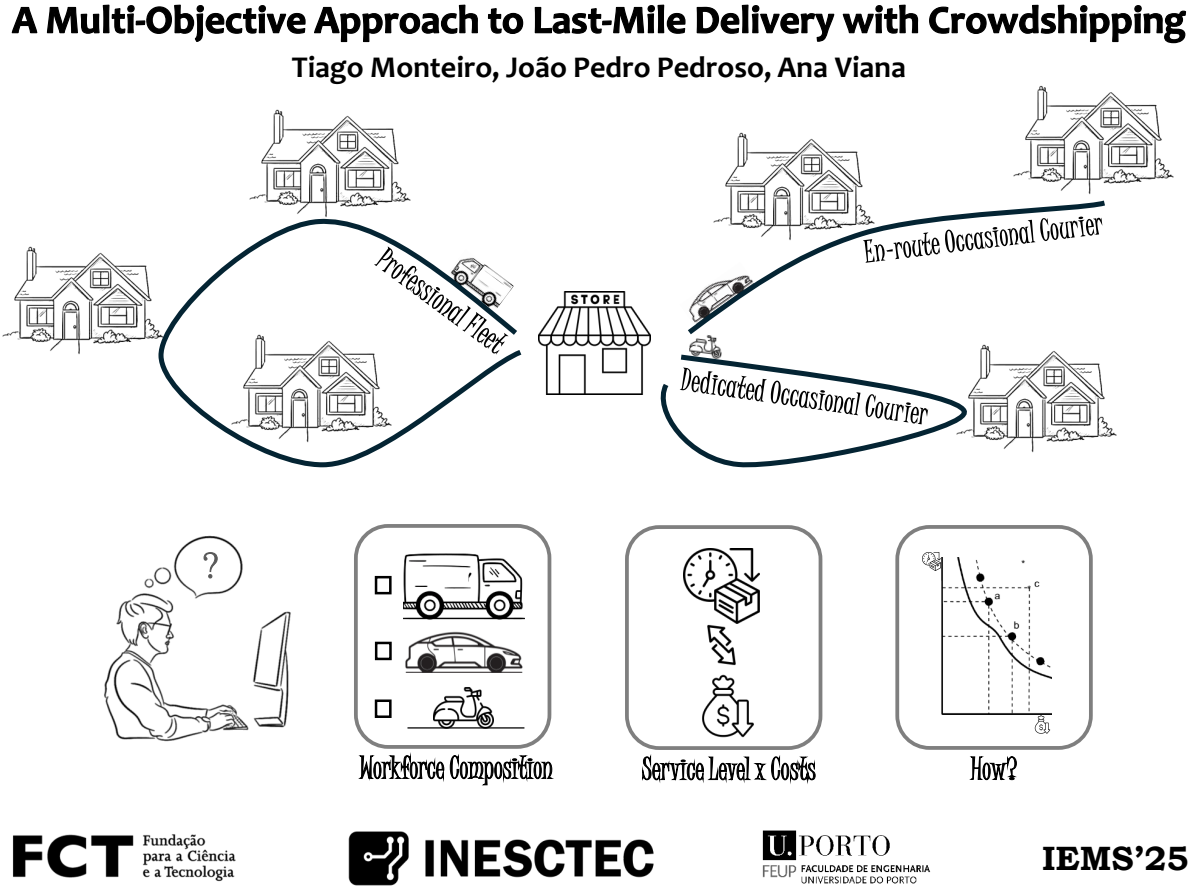

1 The Challenge

E-commerce already accounts for 20% of global retail sales, demonstrating how the digital era has changed how people purchase their goods. With just a few clicks on their electronic devices, customers can browse, buy, and receive nearly any product in the convenience of their homes. This paradigm shift in customer behavior has intensified pressure on supply chain networks that, to satisfy customer expectations of reliable and fast deliveries, are forced to increase efficiency when using existing infrastructures and to design innovative strategies to remain competitive.

This work focuses on the last-mile delivery stage of the supply chain. Last-mile is the last stage of a product's journey from the seller's warehouse to the customer's location. It is a crucial stage of the supply chain since not only it is the most expensive part, but it is also the part customers better perceive and are more sensitive to the level of service.

A novel solution for last-mile delivery is based on crowdshiping. In this solution, packages are delivered to customers by leveraging non-professional couriers ("crowd"), commonly referred to as occasional couriers (OCs), who are ordinary people with no professional relation with the retailers who agree to deliver goods to the final customer for a financial compensation. Platforms such as Amazon Flex and Roadie are examples of crowdshipping platforms. To expand the delivery capacity, Amazon Flex enables non-professional couriers (independent individuals) to use their vehicles to deliver parcels on a flexible schedule. Roadie connects businesses and individuals with drivers already traveling toward their delivery location. Both services exemplify the rise of gig economy-based logistics, which can offer cost-saving benefits for companies and flexible earning opportunities for couriers.

Crowdshipping represents an innovative and attractive delivery approach. It can surpass traditional methods, particularly in urban areas, since occasional couriers can lead to faster and more affordable deliveries. However, as the company does not employ the occasional couriers, the delivery capacity is no longer under its control. This represents a challenge to retailers since, if they decide to have a delivery strategy based on crowdshipping, it is mandatory to assess the number of potential OCs required to ensure that deliveries are made without compromising the service level.

In this work, we present a decision-making tool designed to assess the impact of different workforce compositions on operational costs, service levels, and total travel distance. Specifically, we examine a scenario in which customer deliveries can be fulfilled by a combination of retailers' delivery fleets (professional fleet), en-route occasional couriers (in-store customers making deliveries on their way home), and dedicated occasional couriers (platform-registered individuals accepting delivery tasks). Given the NP-hard nature of this problem, exact methods can only solve small to medium-sized instances. To accommodate larger customer instances, we aim to develop a heuristic-based approach that efficiently identifies near-optimal solutions, striking a balance between the competing objectives of service level and cost (approximate Pareto front).

2 The Methodology

In previous research, we propose a mixed-integer programming model that integrates dedicated and en-route occasional couriers (OCs) into the traditional vehicle routing problem. The distribution network is represented by a directed graph where nodes represent stores, online customers, and final destination points for en-route OCs. Online customers are characterized by their location, demand, and time window constraints. Occasional couriers have limited capacity and time window restrictions. To incorporate customer satisfaction, we adopt a multi-objective approach: minimization of total delivery cost and maximization of service level. The first objective function minimizes total delivery cost, encompassing professional fleet, en-route OC, and dedicated OC costs, while the second maximizes the service level by minimizing total time window deviations.

In this work, we build upon previous research, which demonstrated that exact methods can optimally solve only small and medium-sized instances of the problem by developing a heuristic-based approach to tackle larger instances effectively. The literature presents several metaheuristics designed for problems with multiple objectives. Examples include the Non-dominated Sorting Genetic Algorithm II (NSGA-II), a widely used evolutionary algorithm that employs non-dominated sorting and crowding distance to preserve diversity among solutions on the Pareto front, and Multi-Objective Simulated Annealing (MOSA), which extends the traditional simulated annealing framework to include multiple objectives during the search for optimal solutions.

We implemented a local search heuristic based on the Greedy Randomized Adaptive Search Procedure (GRASP), employing traditional improvement heuristics that incorporate intra-route operators such as relocate, exchange, and 2-opt, as well as inter-route operators like insert and swap. This preliminary methodology enabled us to successfully generate an approximate Pareto front, allowing us to explore the trade-offs between the competing objectives. An example is illustrated in Figure 1, where the true Pareto front (circles) and the approximate Pareto front (crosses) are shown for an instance with 15 online customers and a workforce comprising a professional fleet and en-route OCs. Our heuristic successfully identified three of the four solutions on the Pareto front, which were obtained through exact methods. We intend to expand this work by designing new improvement heuristics and examining the balance between exploration and exploitation within metaheuristic executions since this balance becomes particularly critical in a multi-objective context.

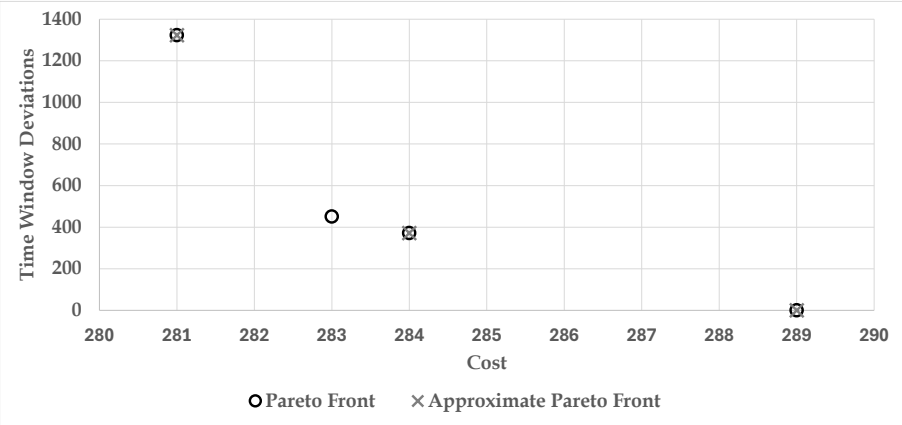

Figure 1: Example of solution.

3 The value to Society

This work enables companies to explore the integration of crowdshipping for last-mile delivery as a viable alternative or complement to their existing delivery strategies. Crowdshipping presents promising advantages, including reduced last-mile delivery costs, decreased environmental impact, and flexible employment opportunities. However, it also poses challenges, such as the effective integration of both types of occasional couriers and ensuring consistent service quality standards. We propose a multi-objective approach focused on two primary goals: minimizing costs and maximizing service level. With the aim of providing a practical method, we develop a heuristic-based approach to efficiently address larger instances. We expect this approach to achieve a reasonable approximation of the Pareto front.

Morning Round table

Shaping the Future of Mobility: Governance, Innovation, and Interdisciplinary Approaches

Ana Paula Vitorino[a], José Gomes Mendes[b], Paulo Humanes[c]
Moderator: Marta Campos Ferreira[d]

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Synopsis: This round table brings together leading experts in mobility, urban planning, and transportation governance to explore the evolving landscape of sustainable and efficient mobility. Ana Paula Vitorino, José Gomes Mendes, and Paulo Humanes will share insights drawn from their extensive academic, professional, and policymaking experiences. Topics will include the role of interdisciplinary collaboration, the integration of transport systems with urban development, and the governance challenges of fostering sustainable and equitable mobility solutions in a rapidly changing world.

Ana Paula Vitorino

Since 2021, she serves as the President of the Board of Directors of the Mobility and Transport Authority. She graduated in Civil Engineering, in the Urbanisation and Transport branch, from the Instituto Superior Técnico (IST). She also specialised in the Organisation and Management of Transport Companies and holds a master's degree in Transport from IST. She has been an Associate Professor at IST since 1989 and researches at CESUR - Centre for Urban and Regional Systems. She has been a member of parliament since 2009. Between 2005 and 2009 she was Secretary of State for Transport and from 2015 to 2019 she was Minister of the Sea.

José Gomes Mendes

José Gomes Mendes is currently the President of Fundação Mestre Casais and a Full Professor of Regional and Urban Systems at the University of Minho. He served as Secretary of State for Enviroment and Mobility in the XXI Portuguese Government, Secretary of State for Planning in the XII Government (2015-2020), and member of the Parliament (2021). He was Chairman of the Transport Decarbonisation Alliance (2017-2019), Vice-Rector at the University of Minho (2009-2015), and Independent Expert and Project Evaluator for the following European Commission agencies (2001-2009): DG Research, (Brussels), European Training Foundation (Torino), Education, Audiovisual and Cultural Executive Agency (Brussels). As a professor and researcher, he worked at several universities in Italy, Poland, the United States of America, Brazil and Mozambique. He is the author of more than a hundred scientific articles and books in the area of cities, transport and sustainability. He received the following awards: Personality of the Year of Portugal Smart Cities (Lisbon, 2024), Personality of the Year of the Fleet Magazine (Lisbon, 2019), Sendai Prize (Japan, 2003), António d'Almeida Foundation Award (Porto, 1989), Minho Industrial Association Award (Braga, 1987). JoséMendes is a civil engineer with a PhD in Urban and Regional Systems and holds postgraduate degrees from the Universities of Oxford, Harvard and ISCTE.

Paulo Humanes

He is currently responsible at the LOGIT consulting firm. Holds a Master's degree in Engineering from the University of Newcastle upon Tyne. Became technical director at Jacobs, one of the world's largest engineering consultancies, focusing on cities, transport infrastructure and road safety. In 2010 he moved to Germany, where he worked at PTV group, a company owned by Porsche SE, where he became responsible

for the Business Development and New Mobility areas. There he developed projects with institutions, governments and cities around the world in the area of sustainable, efficient and safe transport solutions, and later in transport digitalisation with car manufacturers. Returned to Portugal in 2021, to be the director responsible for the Mobility, Automotive and Cities area at CEiiA (Centre for Engineering and Development), Porto.

Marta Campos Ferreira

Marta Campos Ferreira is an Assistant Professor at Faculty of Engineering of University of Porto and a Senior Researcher at INESC TEC. She holds a PhD in Transportation Systems from the Faculty of Engineering of University of Porto (MIT Portugal Program). She has been involved in several R&D projects in areas such as technology enabled services, transport and mobility, with enormous impact on the economy and society and which resulted in several functional prototypes. The prototype developed under the Anda project gave rise to a mobile payment service for public transport in the Porto Metropolitan Area, in Portugal, which has been available to the public since June 2018 and is used daily by thousands of citizens.

Afternoon Round table

Porto, January 7th, 2025

Beyond the Thesis: The Lasting Impact of a PhD Journey on Professional Success

Luiz Henrique Cherri[a], Cristiane Ferreira[b], António Almeida[c], Pierre Polzin[d]
Moderator: Bernardo Almada-Lobo[e]

[a]*Newfoundland Capital Management,* [b]*Amazon,* [c]*INESC TEC,* [d]*Portuguese Health Regulatory Authority,* [e]*INESC TEC, FEUP*

Synopsis: In this roundtable, we will explore how pursuing a PhD at DEGI influence professional success. To that end, four PhD laureates in Industrial Engineering and Management, who have worked or are currently working in the industry, have been invited to share their experiences and evaluate the impact of their PhD projects on their careers.

Luiz Henrique Cherri

Luiz began his academic journey in 2007 at ICMC - USP, focusing on applied mathematics in Scientific Computing. Since then, he has completed multiple academic degrees, including master's, doctoral, and postdoctoral studies, predominantly at the University of São Paulo and partially at the University of Porto. With a dual Ph.D. in Computer Science and Computational Mathematics from USP and Industrial Engineering and Management from the University of Porto, Luiz has dozens of scientific articles with hundreds of citations. He also conducted numerous courses and lectures and mentored master's students. In 2017, Luiz founded his first company, transitioning from academia to the business world. Since then, he has been involved in dozens of consultancy projects, highlighting two notable endeavors: one focused on agricultural planning to maximize farm profits and another in the financial market, leading to the establishment of a quantitative investment management firm to which Luiz currently dedicate his full time.

Cristiane Ferreira

Cristiane has completed a Bachelor in Computer Science at the Universidade Federal de Alagoas, Brazil (2005), and a Master in Computer Science at the Universidade Federal Fluminense, Brazil (2007). Cristiane worked as an Optimization Analyst and Manager at Gapso (now Accenture) for 10 years before returning to academia to complete her Ph.D. in Industrial Engineering and Management at the University of Porto, Portugal (2022), with a project entitled Scheduling in Collaborative and Dynamic Environments. Afterward, Cristiane returned to the business sector to work at Amazon. She has been working there for over 3 years and is currently a Senior Applied Scientist.

António Almeida

António Almeida is the Co-Coordinator of the Center for Industrial Engineering and Management (CEGI) at INESC TEC, where he has been contributing since 2010. With over 15 years of experience, António specializes in project management, solution architecture, and the development of innovative digital products across fields such as retail and e-commerce, Industry 4.0, industrial automation and control, and logistics. António holds a Ph.D. in Industrial Engineering and Management from FEUP, completed in 2014. His doctoral research focused on predictive performance management methods, utilizing machine learning algorithms and complex systems modeling to address industrial challenges. He has published extensively in peer-reviewed international journals and conferences and has actively participated in numerous national and European R&D projects. In addition to his academic and research roles, António has significant industry experience. He served as an E-commerce Business Partner at Continente Online

and as Principal Product Manager for Farfetch, where he spearheaded logistics and supply chain product innovations.

Pierre Polzin

Pierre Polzin is an Economist with an MBA from IBMEC, a Masters in Economics from UFRJ, and a PhD in Industrial Engineering and Management from FEUP. He is a Reviewer for the Journal of Management and Sustainability. Pierre currently works as a Senior Specialist Regulatory Technician in the Health Studies and Evaluation Department of the Health Regulatory Authority (ERS), having been an Advisor to the Board of Directors. He was responsible for the application of three projects to the support system for the digital transformation of Public Administration, SAMA 2020. Pierre is a Guest Assistant Professor on the Postgraduate Management course at the Escola Superior de Saúde de Santa Maria. He was a member of INESC TEC, an economist with an FCT research grant at FEP and an economist with a CAPES research grant at UFRJ. He was responsible for the Country Risk Unit and a voting member of the Credit Committee at *Seguradora Brasileira de Crédito à Exportação*. He was a member of the Supervisory Board of the José Ricardo Foundation, now the Funjor Institute. Pierre was the General Director of Infopulse Brazil and a consultant for the Dutch group Infopulse.

Bernardo Almada-Lobo

Full Professor at Industrial Engineering and Management Department, FEUP. Co-founder of LTPlabs. Member of the Board of Trustees ("conselho de curadores") of Fundação Belmiro de Azevedo. Former Member of the Board at INESC TEC Technology and Science. His main area of activity is Management Science/Operations Research. He develops and applies advanced analytical models and methods to help make better decisions, solving managerial problems in various domains, with a special focus on Operations Management. Degree in Management and Industrial Engineering, FEUP. PhD in Industrial Engineering and Management, UP. Advanced Management Program from INSEAD. Certified Analytics Professional from The Institute for Operations Research and the Management Sciences.