IO 2025 XXIV CONGRESSO APDIO

A IO para um empreendedorismo sustentável

Amarante, 7 a 9 de setembro de 2025

Livro de Resumos

Abstract Book

XXIV Congresso da Associação Portuguesa de Investigação Operacional

Livro de Resumos

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Teresa Pereira

Amarante

7 a 9 de setembro 2025

XXIV Congresso da APDIO

Organizado por três escolas do **Instituto Politécnico do Porto (ESTG, ISCAP e ISEP)** com o apoio da **Câmara Municipal de Amarante.**

APDIO
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INVEST AMARANTE

Conteúdo

Mensagem do Presidente da Direção da APDIO

Caras e caros participantes no IO'2025,

Sejam bem-vindos ao XXIV Congresso da Associação Portuguesa de Investigação Operacional – IO'2025.

O nosso congresso constitui o ponto de encontro mais importante da comunidade portuguesa de Investigação Operacional. Mantemos a tradição do reencontro académico, profissional e pessoal, num ambiente de dinâmica inclusiva, enriquecido pela chegada de novos participantes e pela energia vivida nas sessões científicas, nas interações sociais e no ambiente acolhedor cuidadosamente preparado pela Comissão Organizadora.

O congresso deste ano dá continuidade ao formato de sessões paralelas, organizadas com coerência temática graças ao trabalho da Comissão de Programa. O elevado número de submissões, o entusiasmo gerado em torno do EstudIO e a forte adesão de participantes são reflexo da vitalidade e renovação constante da Investigação Operacional em Portugal.

O tema do IO'2025 — "A IO para um Empreendedorismo Sustentável" — destaca o papel da IO no apoio à criação de valor sustentável, através de modelos e métodos que promovem a inovação responsável, a eficiência na utilização de recursos e a tomada de decisões fundamentadas considerando as vertentes económica, social e ambiental. As sessões plenárias e muitas das comunicações em sessões paralelas trarão exemplos inspiradores de como a IO pode contribuir para um empreendedorismo mais consciente e transformador.

Teremos duas sessões plenárias: pela Prof. Maria Paola Scaparra (EURO Plenary Speaker) sobre o uso da IO para lidar com problemas na área da saúde e desafios climáticos no Sul global, e pelo Dr. Fernando Belezas sobre a seleção de startups, performance e impacto de incubadoras de empresas. Estas sessões visam promover a partilha de visões estratégicas e experiências relevantes no âmbito do tema do congresso, reforçando a ligação entre a comunidade académica, o tecido empresarial e o território.

O EstudIO, com o patrocínio da LTPLabs, continua a ser um espaço privilegiado para os estudantes de licenciatura e mestrado apresentarem os seus trabalhos, num ambiente de valorização e partilha, com destaque próprio no programa científico. O melhor trabalho, escolhido pela votação dos participantes no congresso, terá a oportunidade de conhecer na LTPLabs a aplicação da IO e IA ao serviço de desafios concretos do mundo dos negócios.

A vertente internacional do IO é novamente reforçada com a presença de representantes da SEIO (Espanha) e da SOBRAPO (Brasil) na Comissão de Programa, e com a participação ativa de investigadores dessas comunidades, reforçando laços e estimulando futuras colaborações. De salientar ainda a colaboração com a Sociedade Portuguesa de Estatística, que organiza uma sessão no IO'2025, sendo a APDIO responsável por uma sessão no congresso da SPE em Outubro próximo.

Na sessão de encerramento, teremos a distinção do mérito académico e científico através do Prémio Isabel Themido 2025, que se destina a galardoar os melhores artigos publicados por sócios da APDIO em revistas internacionais no período 2022-2024.

O congresso realiza-se pela primeira vez na cidade de Amarante, prosseguindo o compromisso da APDIO com a descentralização e o envolvimento de diferentes regiões na dinamização da nossa área científica. Que a beleza serena de Amarante seja inspiradora, que seja inspirador ter nascido aqui um artista genial, Amadeo de Souza-Cardoso, que entre Manhufe e Paris produziu o mais intenso diálogo entre uma certa ruralidade nortenha e as vanguardas artísticas do início do século XX.

Em nome da Direção da APDIO, agradeço reconhecidamente à Comissão Organizadora, presidida pela Prof.ª Sara Martins, do Instituto Politécnico do Porto, à Comissão de Programa, liderada pelo Prof. Luís Dias, da Universidade de Coimbra, bem como a todas as entidades que contribuíram para o sucesso do

IO'2025, com especial destaque para a Câmara Municipal de Amarante pela hospitalidade.

Em nome da Direção da APDIO, desejo a todas e a todos um congresso produtivo e enriquecedor — uma oportunidade para partilhar conhecimento, reforçar laços e impulsionar novas ideias e projetos com impacto no bem-estar inclusivo e com respeito pelo meio ambiente.

Com cordiais cumprimentos do

Carlos Henggeler Antunes

Presidente da Direção da APDIO

Nota do Presidente da Comissão de Programa

É um grande prazer dar-vos as boas vindas ao XXIV Congresso da Associação Portuguesa de Investigação Operacional (IO2025). Trata-se do principal ponto de encontro desta comunidade, simultaneamente diversa e coesa, a nossa comunidade de Investigação Operacional. Nesta edição, o tema é "A IO para um empreendedorismo sustentável". Pensamos naturalmente na criação de empresas que criam soluções baseadas na IO ou no uso da IO para apoiar o desenvolvimento de novos negócios ou clusters de empreendedorismo. Mas pensamos igualmente na Administração Pública, nas pequenas e nas grandes empresas, e em todas as organizações em geral, onde a aplicação da IO é também um ato de empreender: precisamos de muitos empreendedores de IO para que se desenvolvam de forma sustentável.

A abrir o congresso teremos, pela primeira vez, uma EURO Plenary Session patrocinada pelo EURO, na qual a Maria Paola Scaparra, Professor of Management Science e Associate Dean for Research and Innovation na Universidade de Kent, falará sobre como a IO contribui para enfrentar desafios de saúde e de alterações climáticas no sudeste asiático e em África.

No segundo dia teremos as sessões paralelas, num total de 23, que organizam tematicamente as 81 comunicações aceites. Contaremos novamente com oradores que falam outras línguas que não a portuguesa, pelo que teremos a indicação de algumas sessões decorrerem em inglês, deixando nas outras liberdade para que as apresentações decorram em português ou inglês. Uma das sessões é coorganizada pela Sociedade Portuguesa de Estatística, numa parceria que se saúda e que realça as pontes entre as áreas da Estatística e da IO, também visíveis em várias outras sessões. Deixa-se ao cuidado de cada participante resolver o exercício de otimização, porventura multiobjetivo, do conjunto de sessões a que irá assistir!

Beneficiando da insubstituível experiência transmitida pela Comissão de Programa do IO2024, presidida pela nossa colega Maria Antónia Carravilla, e que muito facilitou a nossa organização, temos algumas sessões mais curtas, e temos também sempre um pequeno intervalo entre sessões. Tal permitirá uma pausa para mudar de sala, ou para ficar a conversar com os oradores, ou amortecer algum pequeno atraso sem perturbar a sessão seguinte. Tal como no congresso anterior, manteremos a alocação de 15 minutos por comunicação, apontando para ter apresentações de 12 minutos e 3 minutos para algumas questões rápidas. Para as questões mais longas, o programa deixou amplo espaço em pausas para café e para almoço.

No terceiro dia teremos o EstudIO, organizado pelas colegas Beatriz Brito Oliveira e Maria João Santos, onde ouviremos os 10 trabalhos selecionados de estudantes de licenciatura ou mestrado, numa sessão que há muito deixou de ser paralela para se tornar uma sessão plenária muito acarinhada pela nossa comunidade. Seguir-se-á a apresentação plenária de encerramento por Fernando Belezas, diretor geral executivo do Instituto Empresarial do Tâmega, acerca da seleção de startups e mensuração do impacto no contexto de incubação de empresas. Teremos, por fim, o aguardado momento de atribuição dos prémios EstudIO e Isabel Themido, na sessão de encerramento.

Cabe-me agradecer a inestimável ajuda de todos os membros da Comissão de Programa e a excelente colaboração com a Comissão Organizadora presidida por Sara Martins. Agradeço ainda a todos os moderadores de sessões, bem como aos oradores e coautores pela generosa contribuição do seu trabalho. E agradeço sobretudo, por antecipação, a vossa presença, as trocas de ideias, a amizade e as memórias que marcam os nossos congressos. Estamos ansiosos por nos encontramos em Amarante!

Pela Comissão de Programa

Luís Cândido Dias

Comissão Organizadora

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Aldina Correia - CIICESI, ESTG, Instituto Politécnico do Porto

Ana Maria Rodrigues - INESC TEC, CEOS.PP, ISCAP, Instituto Politécnico do Porto

Cristina Lopes - CEOS.PP, ISCAP, Instituto Politécnico do Porto

Eliana Costa e Silva - CIICESI, ESTG, Instituto Politécnico do Porto

Marisa Guerra Pereira - LAETA-INEGI, ISEP, Instituto Politécnico do Porto

Sofia Cruz Gomes - INESC TEC, ESTG, Instituto Politécnico do Porto

Teresa Pereira - LAETA-INEGI, ISEP, Instituto Politécnico do Porto

Comissão de Programa

Luís Dias (Presidente) - Faculdade de Economia da Universidade de Coimbra

Ana Sara Costa Domingues - Universidade de Évora

Ana Sofia Pereira - Widescope

Beatriz Brito Oliveira - Universidade do Porto, Faculdade de Engenharia

Carina Pimentel - Universidade do Minho, Escola de Engenharia

Carla Geraldes - Instituto Politécnico de Bragança

Elsa Silva - Universidade do Minho, Escola de Engenharia

Inmaculada Rodríguez Martín - Universitas Miguel Hernandez

Isabel Cristina Lopes - CEOS.PP, ISCAP, Instituto Politécnico do Porto

Isabel Gomes - Universidade Nova de Lisboa, Faculdade de Ciências e Tecnologia

Maria Antónia Carravilla - Universidade do Porto, Faculdade de Engenharia

Maria Cândida Mourão - Universidade de Lisboa, ISEG

Maria João Alves - Universidade de Coimbra, Faculdade de Economia

Maria João Santos - INESC TEC

Miguel Constantino - Universidade de Lisboa, Faculdade de Ciências

Paula Sarabando - Instituto Politécnico de Viseu

Pedro Martins - Instituto Politécnico de Coimbra, ISCAC

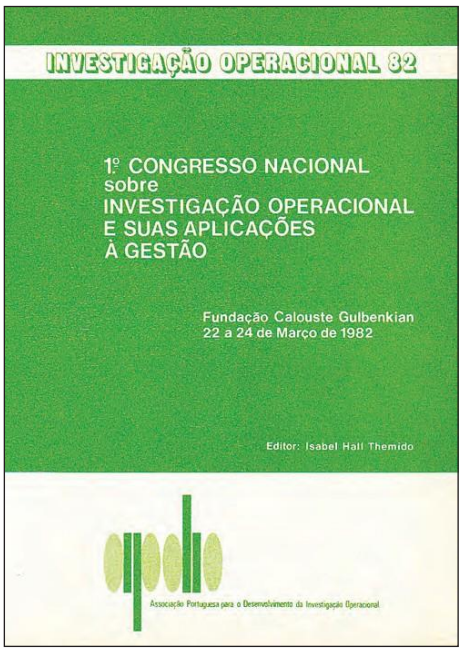
Rui Borges Lopes - Universidade de Aveiro, DEGEIT

Samuel Moniz - Universidade de Coimbra, Faculdade de Ciências e Tecnologia

Sara Martins - Instituto Politécnico do Porto, ESTG

Susana Relvas - Universidade de Lisboa, Instituto Superior Técnico

Edições Anteriores



1º Congresso da APDIO

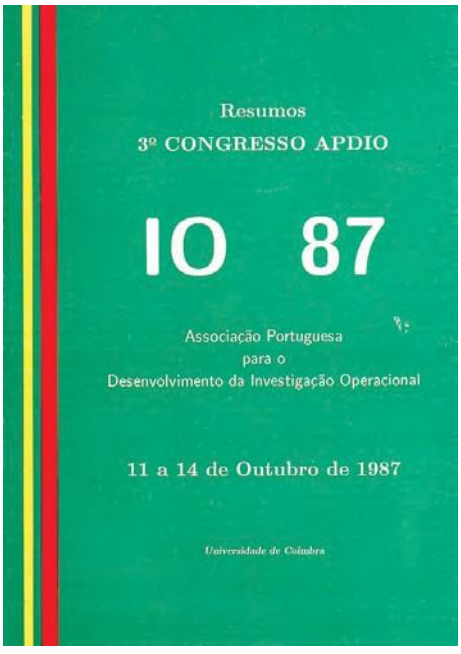
Lisboa, 22 a 24 de março de 1982
Fundação Calouste Gulbenkian

Presidente da Comissão Organizadora
Aníbal Durães Santos

2º Congresso da APDIO

Porto, 16 a 18 de abril de 1984
Faculdade de Economia da Universidade do Porto

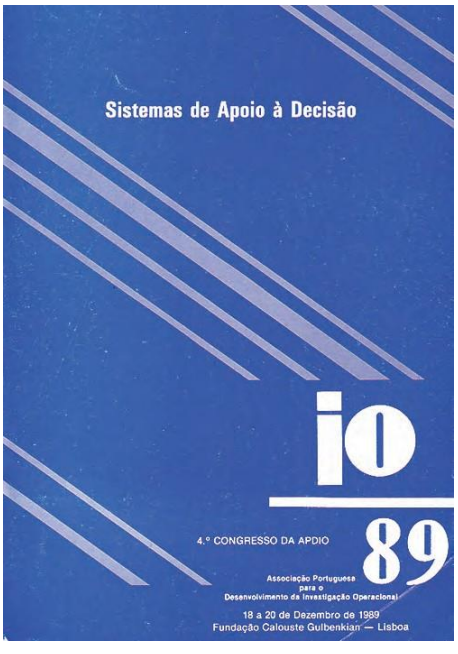
Presidente da Comissão Organizadora
Rui Guimarães



3º Congresso da APDIO

Coimbra, 11 a 14 de outubro de 1987
Universidade de Coimbra

Presidente da Comissão Organizadora
Mário da Silva Rosa



4º Congresso da APDIO

Lisboa, 18 a 20 de dezembro de 1989
Fundação Calouste Gulbenkian

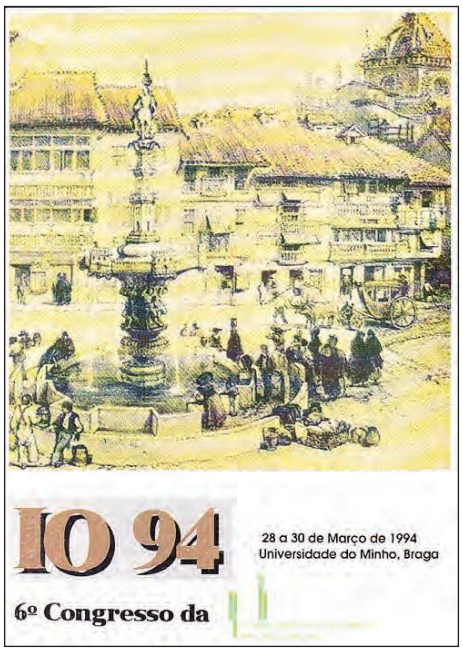
Presidente da Comissão Organizadora
A. J. Simões Monteiro

5º Congresso da APDIO

Évora, 13 a 15 de abril de 1992
Universidade de Évora

Presidente da Comissão de Programa
José Rodrigues Dias

Presidente da Comissão Organizadora
Rui Guimarães



6º Congresso da APDIO

Braga, 28 a 30 de março de 1994
Universidade do Minho

Presidente da Comissão de Programa
Jorge Pinho de Sousa

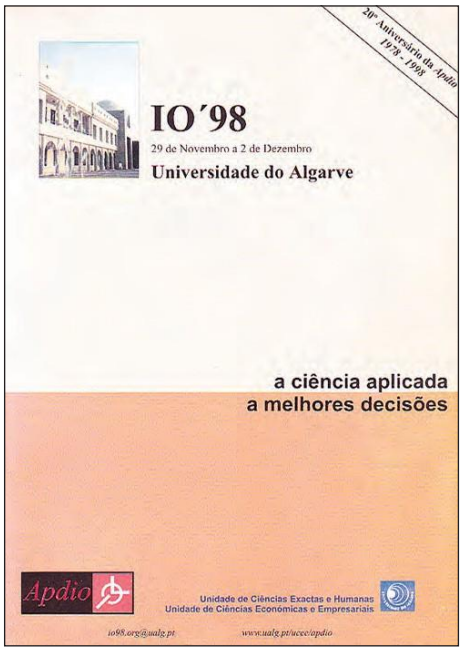
Presidente da Comissão Organizadora
A. Guimarães Rodrigues

7º Congresso da APDIO

Aveiro, 1 a 3 de abril de 1996
Universidade de Aveiro

Presidente da Comissão de Programa
Carlos Bana e Costa

Presidente da Comissão Organizadora
Domingos Moreira Cardoso

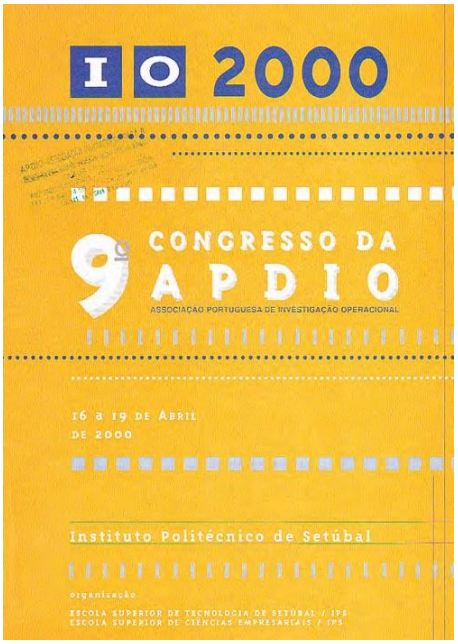


8º Congresso da APDIO

Faro, 29 de novembro a 2 de dezembro de 1998
Universidade do Algarve

Presidente da Comissão de Programa
José Pinto Paixão

Presidente da Comissão Organizadora
Fernanda Marília Pires

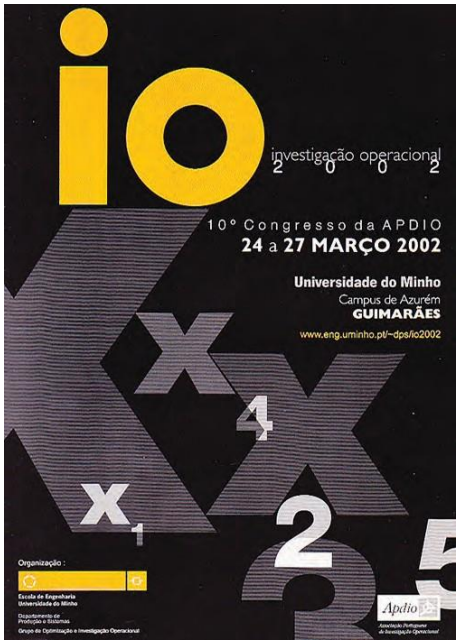


9º Congresso da APDIO

Setúbal, 16 a 19 de abril de 2000
Instituto Politécnico de Setúbal

Presidente da Comissão de Programa
Carlos Henggeler Antunes

Presidente da Comissão Organizadora
Carlos Luz



10º Congresso da APDIO

Guimarães, 24 a 27 de março de 2002
Universidade do Minho

Presidente da Comissão de Programa
José Fernando Oliveira

Presidente da Comissão Organizadora
José Valério de Carvalho

11º Congresso da APDIO

Porto, 4 a 7 de abril de 2004
Faculdade de Engenharia da Universidade do Porto

Presidente da Comissão de Programa
Joaquim João Júdice

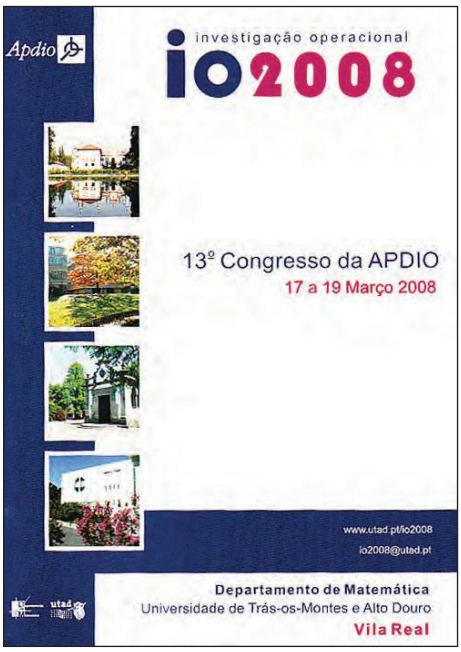
Presidente da Comissão Organizadora
Rui Guimarães

12º Congresso da APDIO

Lisboa, 8 a 11 de outubro de 2006
ISEG - Universidade Técnica de Lisboa

Presidente da Comissão de Programa
Pedro Oliveira

Presidente da Comissão Organizadora
Margarida Vaz Pato

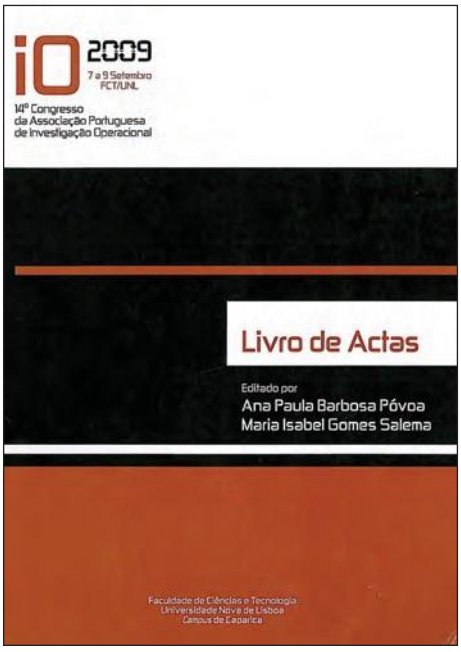


13º Congresso da APDIO

Vila Real, 17 a 19 de março de 2008
Universidade de Trás os Montes e Alto Douro

Presidente da Comissão de Programa
Maria Eugénia Captivo

Presidente da Comissão Organizadora
Ana Paula Teixeira

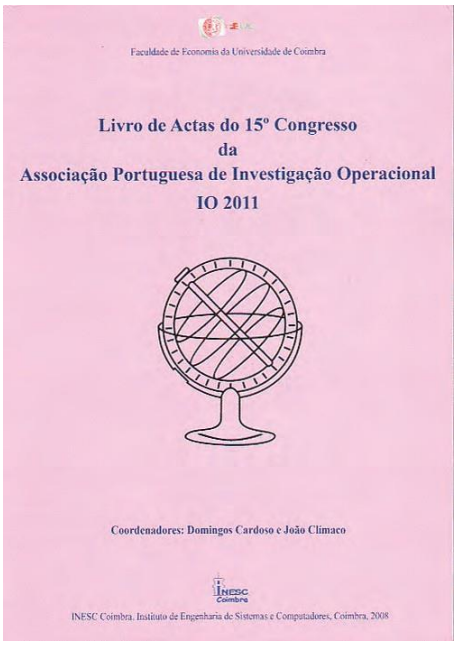


14º Congresso da APDIO

Caparica, 7 a 9 de setembro de 2009
FCT - Universidade Nova de Lisboa

Presidente da Comissão de Programa
Ana Barbosa Póvoa

Presidente da Comissão Organizadora
Ruy Costa



15º Congresso da APDIO

Coimbra, 18 a 20 de abril de 2011
Universidade de Coimbra

Presidente da Comissão de Programa
Domingos Moreira Cardoso

Presidente da Comissão Organizadora
João Clímaco

16º Congresso da APDIO

Bragança, 3 a 5 de junho de 2013
Instituto Politécnico de Bragança

Presidente da Comissão de Programa
José Fernando Oliveira

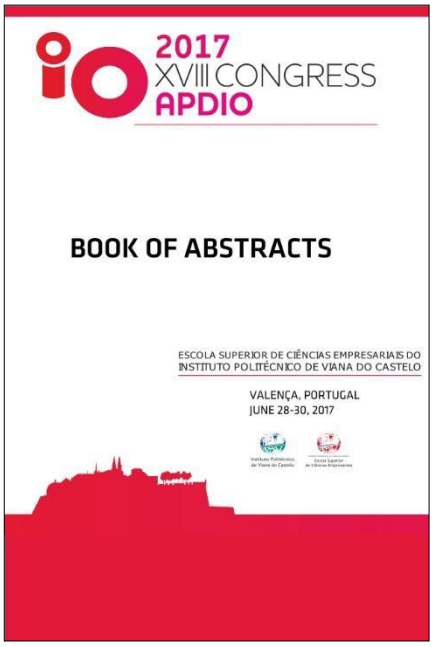
Presidente da Comissão Organizadora
Clara Bento Vaz

17º Congresso da APDIO

Portalegre, 7 a 9 de setembro de 2015
Instituto Politécnico de Portalegre

Presidente da Comissão de Programa
Ana Paula Barbosa-Póvoa

Presidente da Comissão Organizadora
João Luís de Miranda



18º Congresso da APDIO

Valença, 28 a 30 de junho de 2017
Instituto Politécnico de Viana do Castelo

Presidente da Comissão de Programa
António Ismael Freitas Vaz

Presidente da Comissão Organizadora
Lia Oliveira

19º Congresso da APDIO

Aveiro, 5 a 7 de setembro de 2018
Universidade de Aveiro

Presidente da Comissão de Programa
Maria João Alves

Presidentes da Comissão Organizadora
Ana Raquel Xambre
Helena Alvelos

20º Congresso da APDIO

Tomar, 22 a 24 de julho de 2019
Instituto Politécnico de Tomar

Presidente da Comissão de Programa
Susana Relvas

Presidente da Comissão Organizadora
João Patrício

21º Congresso da APDIO

Figueira da Foz,
7 e 8 de novembro de 2021

Presidente da Comissão de Programa
Samuel Moniz

Presidente da Comissão Organizadora
Samuel Moniz

22º Congresso da APDIO

Évora, 6 a 8 de novembro de 2022
Universidade de Évora

Presidente da Comissão de Programa
Jorge Orestes Cerdeira

Presidente da Comissão Organizadora
Cesaltina Pires

23º Congresso da APDIO

Viseu, 24 a 26 de março de 2024
Instituto Politécnico de Viseu

Presidente da Comissão de Programa
Maria Antónia Carravilla

Presidente da Comissão Organizadora
Paula Sarabando

Programa Geral

	Domingo (07/09/2025)	2ª feira (08/09/2025)	3ª feira (09/09/2025)
09:00			
09:15		Sessões Paralelas 1	
09:30			
09:45			
10:00		Intervalo	Plenária EstudIO
10:15		Sessões Paralelas 2	
10:30			
10:45			
11:00		Coffee-Break | ESTG	
11:15			
11:30		Sessões Paralelas 3	Coffee-Break
11:45			
12:00			Plenária
12:15			
12:30		Almoço	
12:45			Sessão de Encerramento
13:00			
13:15			
13:30			Almoço
13:45			
14:00			
14:15		Sessões Paralelas 4	
14:30	Receção dos Participantes		
14:45			
15:00			
15:15		Intervalo	Trilho junto ao rio
15:30	Sessão de Abertura	Sessões Paralelas 5	
15:45			
16:00			
16:15	The EURO Plenary		
16:30		Coffee-Break | ISEP	
16:45			
17:00		Assembleia Geral	
17:15	Peddy Paper IO por Amarante		
17:30			
17:45			
18:00			
18:15			
18:30	Verde D'Honra		
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19:30		Autocarro	
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20:00		Jantar do Congresso	
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Sessões Plenárias

Sessão Plenária I | EURO Plenary

Using OR to tackle health and climate challenges in the Global South

Maria Paola Scaparra
Kent Business School, University of Kent

The 2030 Agenda for Sustainable Development presents an ambitious call to action for ending poverty, improving health and well-being, and addressing the climate emergency. These global challenges are especially acute in the Global South, where systemic vulnerabilities and resource constraints demand innovative, context-sensitive solutions. Operational Research, and optimisation in particular, can play a critical role in shaping data-driven, locally grounded interventions that build resilience and promote sustainable development.

In this talk, I will present some research projects that apply OR to real-world development challenges in Southeast Asia and Sub-Saharan Africa. Specific examples include designing adaptive flood mitigation strategies for rapidly urbanising cities in Vietnam (the GCRF-OSIRIS project), building OR research capacity for sustainable development in Southeast Asia (CREST-OR project) and optimising health delivery in refugee camps in Ethiopia (a collaboration with Doctors with Africa CUAMM).

Rather than focusing solely on technical results, I will reflect on what these projects have taught us about the importance of people-centred, interdisciplinary approaches. The aim of the talk is to highlight how Operational Research, when embedded in real-world collaborations, can make a tangible difference to the lives of vulnerable communities and contribute to a more resilient and sustainable future.

Maria Paola Scaparra is Professor of Management Science and Associate Dean for Research and Innovation at Kent Business School, University of Kent, UK. She has held a range of leadership positions within the School, including Head of the Management Science Group and Programme Director for the MSc Business Analytics.

Paola holds an M.S. in Management Science and Engineering from Stanford University and a Ph.D. in Mathematics Applied to Economic Decisions from the University of Pisa, Italy. Her research focuses on the development of advanced operational research models to address real-world challenges in critical infrastructure protection, disaster management, healthcare, and sustainable development.

Paola is passionate about using analytics and optimisation to tackle complex problems in low-resource settings and to support the United Nations Sustainable Development Goals. She has led and collaborated on numerous international, interdisciplinary, and policy-focused projects, funded by the Engineering and Physical Sciences Research Council, the British Academy, the British Council, and Innovate UK.

Sessão Plenária II | Plenary

Startup selection, performance, and impact of business incub

Fernando Belezas
IET – Instituto Empresarial do Tâmega

Business incubators are often seen as essential tools for fostering startup success and driving regional economic development. But how much of that impact is real, and how much is assumed? In this plenary session, I will share a reflection grounded in empirical data and hands-on experience on how incubation programs can — or sometimes cannot — make a meaningful difference for startups.

We will explore key issues around startup selection criteria, performance metrics, and the real challenges of evaluating the territorial impact of incubation initiatives. Combining practical insights with quantitative analysis, this talk aims to question some common assumptions about incubation ecosystems and the way we measure their effectiveness. Using real-world examples and comparative data, we will discuss when and how incubation adds value. The goal is to contribute to a more rigorous and realistic understanding of what works, what doesn't, and how to design better support systems for entrepreneurship.

Fernando Belezas é diretor geral executivo do IET – Instituto Empresarial do Tâmega. É docente e formador nas áreas da gestão e do direito empresarial. É consultor em estratégia empresarial, inovação e empreendedorismo. É ainda doutorado em Ciências Económicas e Empresariais no Departamento de Economia, Gestão, Engenharia Industrial e Turismo, da Universidade de Aveiro, e mestre em Direito e Gestão pela Escola do Porto da Faculdade de Direito da Universidade Católica Portuguesa. No passado, fundou a Seedimo, uma fintech especializada em investimento imobiliário e exerceu as funções de solicitador num dos maiores gabinetes jurídicos do país. Paralelamente, participou como mentor e formador em diversos programas de empreendedorismo e inovação. A título voluntário foi relator do Observatório dos Direitos Humanos e é membro dos órgãos sociais de diversas associações cívicas e culturais.

Sessão Plenária EstudIO

Moderadoras: Beatriz Oliveira and Maria João Santos

Sessões Paralelas

Sessão 1.1
Optimization-Simulation

Moderador: José Valério de Carvalho

Optimization-Simulation approach for the vehicle routing problem with time windows and synchronized visits under travel and service time uncertainty

Raquel Bernardino, Daniel Santos, Filippo Visintin

In this presentation, we address the vehicle routing problem with time windows and synchronized visits under uncertain service and travel times. Specifically, a subset of clients require simultaneous service by two vehicles, which is initiated only after the arrival of both vehicles and, consequently, enforces a waiting period for the vehicle that arrived earlier. To tackle this problem, we propose an optimization-simulation framework. Through an iterative process, a deterministic optimization model generates potential solutions which are then assessed through a simulation model. If the solution is found to lead to a bad average performance, new constraints and penalties are added to the deterministic optimization model. This iterative process continues until the performance criteria are satisfied. We validate our approach through experiments on benchmark instances from the literature.

Keywords: Routing, Optimization, Simulation

An Optimisation and Simulation Approach for the Design of Demand Responsive Transport Services

Armando Dauer, Teresa Galvão, Jorge Pinho de Sousa, Bruno Prata

Demand-responsive transport (DRT) systems are quite flexible, adapting quickly to changes in demand through dynamic routing, scheduling, and fleet sizing. Unlike conventional public transport, DRT operations are often planned daily, especially in low-demand contexts. However, as demand grows, planning becomes computationally intensive. While effective methods exist in the literature, many are complex and not easily implemented. This work proposes a two-phase heuristic embedded in a simulation-based framework to support the design and operation of DRT services. In the first phase, a constructive algorithm generates feasible routes by sequencing trips to avoid overlaps. The second phase enhances these routes by adjusting pick-up and drop-off times to facilitate ride-sharing and improve vehicle utilization. This optimization component is integrated into a simulation environment that evaluates system performance under varying demand conditions. Preliminary experiments on small-sized instances showed that the heuristic provides high-quality solutions with very low computational effort. The approach offers a balance between simplicity, efficiency, and practical applicability, making it suitable for iterative simulation optimization schemes. This study is part of a broader framework aimed at designing more adaptive and efficient DRT systems.

Keywords: Optimization, Simulation, Transport, Heuristic

A hybrid optimization-simulation framework for sustainable closed-loop supply chains design and planning

Mariana Camarneiro, Bruno S. Gonçalves, Samuel Moniz, Miguel Vieira, Catia da Silva

Sustainability challenges have become a central concern in supply chain design and planning, requiring effective decision-support methods that address economic, environmental, and social objectives. This work proposes a hybrid optimization–simulation framework that combines a mixed-integer linear programming model, used to optimize sustainability goals through a novel practically oriented objective function, with a discrete-event simulation model to assess the solution under uncertain conditions. A closed-loop supply chain design, inspired by the case of a chemical manufacturer, is optimized and subsequently simulated under realistic variability scenarios to yield more feasible sustainable solutions. Results demonstrate how operational decisions, such as workforce expansion, enhance demand fulfillment, while strategies like order consolidation contribute to environmental improvements. The proposed framework provides a structured methodology for evaluating strategic trade-offs across the triple bottom line, offering actionable insights for supply chain managers aiming to align operations with long-term sustainability objectives.

Keywords: Supply Chain, Sustainability, Optimization, Simulation, Trade-Offs

Sessão 1.2
OR in Energy 1

Moderador: Carlos Henggeler Antunes

Optimizing Hybrid Renewable Energy with Tidal and Offshore Wind in the Mersey Estuary

Luciana Yamada, Flávia Barbosa, Luís Guimarães

The River Mersey in Liverpool has long been recognized for its considerable tidal range, offering significant potential for energy generation. However, none of the studies explored integrating tidal and offshore wind energy systems within a hybrid configuration. This study addresses this gap by investigating the integration of these two sources by leveraging the proximity of the existing Burbo Bank Offshore Wind Farm (OWF) to a proposed tidal barrage site. An optimization model is developed to determine the most cost-effective configuration of the tidal barrage by maximizing its net present value. The design variables include the barrage location, the number and type of turbines, and the number of sluice gates. The model accounts for the combined energy contributions from the tidal barrage and the OWF, which share a common export cable that constrains the total energy exported to the grid. The study demonstrates the benefits of hybridizing tidal and wind energy sources in the region, highlighting synergies that can enhance energy reliability and efficiently use existing transmission infrastructure.

Keywords: Renewable Energy, Optimization

An effective hybrid decomposition approach to solve the network-constrained stochastic unit commitment problem in large-scale power systems

Ricardo Pinto de Lima, Antonio Conejo, Gonzalo Constante-Flores, Omar Knio

We propose an effective hybrid decomposition method to solve network-constrained stochastic unit commitment (SNCUC) problems. We address large-scale SNUC cases involving renewable generation units, hundreds of thermal generation units, thousands of transmission lines and nodes, and uncertain renewable generation and demand. The problem is formulated as a two-stage stochastic program with continuous and binary variables in the first stage and only continuous variables in the second stage. We developed a hybrid Benders decomposition that recasts the original SNCUC problem into a novel master problem and subproblems. The proposed master problem encompasses unit commitment decisions and dispatch decisions across all scenarios, resulting in an extended master problem with first- and second-stage variables and constraints. At each iteration, a new column-and-constraint generation step adds selected transmission variables and constraints per scenario to the master problem. Detailed computational results compare the proposed hybrid decomposition performance with the extensive formulation via branch-and-cut and multiple Benders decomposition implementations. The results show that the hybrid decomposition achieves bounds of superior quality and finds solutions for instances where other Benders decompositions fail.

Keywords: Renewable Energy, Optimization, Stochastic, Elecricity

Towards energy transition in the mining supply chain

Linda Canales Bustos, Ana Barbosa-Póvoa

The mining industry plays a crucial role in the global energy transition, which is essential for achieving net-zero carbon emissions. As the main source of critical minerals essential to renewable energy technologies, mining supplies the foundational materials needed for the development and deployment of clean energy solutions. Consequently, the demand for these minerals is projected to grow significantly in the coming years. However, supporting the energy transition poses substantial challenges for the mining sector, including high energy consumption, dependence on fossil fuels, complex supply chains, large-scale technological investments, and significant environmental and social impacts. This research addresses these challenges by proposing an optimization approach to mining supply chain planning that enhances both operational efficiency and sustainability. The study integrates clean-efficient technologies and renewable energy to reduce carbon emissions and improve energy efficiency within mining operations. Recognizing the capital-intensive nature of these initiatives, it emphasizes the importance of long-term strategic planning to ensure economic feasibility and sustainable outcomes. An optimization model is developed for long-term mining supply chain planning, encompassing multiple echelons, periods, and mineral products. A case study of the Chilean mining industry illustrates the practical application of this model, analysing the sector's specific challenges in transitioning to a cleaner energy paradigm. By providing a decision-support tool, this work aims to contribute to the transformation of the mining industry toward sustainability and support the global clean energy transition.

Keywords: Supply Chain, Optimization, Mining, Energy, Sustainability

Sessão 1.3
Scheduling and Transportation

Moderador: Jorge Pinho de Sousa

Rolling stock rotation planning in a regular operation context

Ana Carvalho, Ricardo Pereira, Rita Portugal, Ricardo Saldanha

The rolling stock rotation planning problem with maintenance constraints can be stated in the following way: given a set of train trips each one with its own passenger demand find, from scratch, for a standard week, the most cost-effective rotations that assign a vehicle composition (hereafter composition) to each trip that covers all or part of the demand and that satisfy all operational constraints, namely maintenance constraints and many others. The overall rotation cost includes aspects like track occupation, fleet depreciation, maintenance and energy consumption, crew utilization and uncovered demand. Since the problem cannot be solved exactly, due to the size of problem instances and the complexity of maintenance constraints, we propose approximate solution methods. Our approaches take advantage of splitting the standard week into several subproblems involving one or more days. Furthermore, we consider the trips' regularity, meaning that there are exactly the same set of trips repeated on different days (e.g. weekdays usually have the same timetable every day). Our solution methods were evaluated with problem instances from a European passenger railway operator that provides a regular service with multiple-unit trains. Results highlight the potential of the proposed approaches.

Keywords: Optimization, Heuristic, Rail transport, Scheduling

Enhancing Port Efficiency and Sustainability through Just-in-Time Arrivals and Tugboat Resource Management

Catarina Carvalho, Catarina M. Marques, Jorge Pinho de Sousa

Maritime transport and port operations are vital to global trade but face growing pressure to improve efficiency and lower greenhouse gas (GHG) emissions. Just-in-Time (JIT) arrival offers a promising management solution, involving speed adjustments so that vessels reach the pilot boarding point only when port services are confirmed. This approach aims to cut fuel and emissions by reducing idle time at anchor. However, JIT success depends on efficient tugboat operations, which are essential for berthing and departure. Their effective scheduling is crucial to avoid congestion, especially in high-traffic ports.
In this work a discrete event simulation-based decision-support tool was developed to assess JIT arrival strategies in container terminals, focusing on tugboat resource allocation and scheduling. By modelling port processes and analysing scenarios involving vessel speed optimisation and tugboat availability, the tool evaluates impacts on a set of key performance indicators: waiting times, emissions, and resource utilisation. A case study at a Portuguese seaport shows the effectiveness of the model, revealing notable reductions in emissions and operational inefficiencies. These findings highlight the potential of JIT operations and effective tugboat scheduling to enhance sustainability and efficiency in the maritime sector. Future work will extend the current approach by the adoption of a mixed-integer linear programming model for tugboat scheduling with time constraints.

Keywords: Scheduling, Simulation, Maritime transport, JIT, Sustainability

Improving efficiency in Container Terminals through Coordinated Truck Scheduling: a Heuristic-based Approach

Catarina M. Marques, José Luís Moreira, Jorge Pinho de Sousa

Maritime trade has been continuously growing in the last decades, increasing the pressure on container terminals and intensifying needs for more effective management systems. Inefficiency arises on the landside operations with the increasing number of truck arrivals for the collection and delivery of containers. The highly stochastic nature of truck arrivals leads to an unbalanced workload distribution and inconsistent resource utilization, heavily impacting congestion and overall operational efficiency. Conventional appointment systems still prioritize carrier requests without considering terminal constraints, resulting in a suboptimal truck scheduling performance. To tackle these challenges, a heuristic-based optimization model was developed in this work, to improve the scheduling of container pickups. The model integrates the truck appointment preferences with terminal-related data such as container yard locations, terminal layout, and resources availability. To minimize operating time, the model addresses two core decisions – the assignment of containers to time-windows and the truck pickups sequencing within each time-window. By dynamically reallocating containers within the yard, aiming to minimize relocations and handling times, the heuristic seeks to balance resource utilization and carrier preferences. Preliminary results show the proposed approach reduces operational time, decreases truck waiting times, and enhances terminal throughput, thus contributing to more sustainable and efficient port operations.

Keywords: Scheduling, Heuristic, Optimization, Transport

Sessão 1.4
SPE Session on Statistics

Moderador: Luís Filipe Meira Machado

An Hybrid Neural Network-Optimal Control Approach for Irrigation Scheduling Based on Satellite Data

J.V.S. Loureuro, M. Fernanda P. Costa, S. Faria, C. Ribeiro, Cecilia Coelho

Plantations face significant challenges due to water scarcity and prolonged periods of drought. Currently, irrigation management is mostly performed manually and relies heavily on the experience of farmers, who make adjustments based on the time of year. However, several factors influence irrigation needs, including air and soil humidity, temperature, and the amount of rainfall. Incorporating these variables into irrigation planning is crucial for optimising water use and ensuring efficient resource management, thereby supporting sustainability. Moreover, climate change has led to an increase in extreme weather events and atmospheric instability, making optimal water management even more difficult. In this work, we formulate an optimal control problem that recommends the amount of water to use for irrigation in a given time horizon. To support long-term decision making, we use variables given by a neural network to the optimal control problem. The neural network identifies and models new and complex causal relationships between atmospheric and soil variables from satellite data. Our approach allows for intelligent irrigation management that can anticipate periods of drought or extreme precipitation events.

Keywords: Neural Network , Agriculture, Meteorology, Statistics

Interval-Censored Survival Analysis with Continuous Covariates

Luís Filipe Meira Machado

This work addresses the problem of estimating the conditional survival function when event times are subject to interval censoring and continuous covariates are present. Such data structures arise frequently in real-world operational contexts, including maintenance planning, healthcare monitoring, and quality control systems, where events are only observed within time intervals due to periodic inspections. We propose two nonparametric methodologies based on kernel smoothing and iterative Expectation-Maximization (EM) algorithms. These approaches generalize Turnbull's estimator to the conditional setting and enable flexible estimation without relying on strong parametric assumptions. From an operational research perspective, the ability to accurately model survival probabilities as a function of continuous covariates supports more informed decision-making under uncertainty.

Keywords: Optimization, Statistics

Data-Driven Insights into Trust for Decision-Making in Social Robot Interaction

Flora Ferreira, Estela Bicho, Letícia Cocato, Wolfram Erlhagen, Paulo Vicente

Trust is a key determinant of successful human-robot interaction across diverse application domains. This study investigates the formation of trust in robots through an online experiment where participants viewed curated videos showcasing varied robotic behaviors. Conducted within the I-CATER project, which focuses on social robots in workplace environments, the research explores how communication strategies and social behaviors influence trust perceptions. The video scenarios included differences in error communication, task initiation approaches, and facial expressions. Participants completed a questionnaire integrating the Godspeed Questionnaire Series (GQS) and the Big Five Inventory-10 (BFI-10), supporting a multifaceted assessment of trust-related dimensions. Statistical analyses using Friedman and Wilcoxon tests revealed that verbal justifications and apologies significantly improved perceived likeability and intelligence, while dynamic facial expressions increased perceptions of anthropomorphism, likeability, and animacy. Although demographic factors such as age, technological background, and robot ownership showed no significant correlation with trust, a weak gender trend indicated lower trust ratings among male participants. Clustering analysis further identified distinct participant profiles based on trust responses. The study provides valuable insights to support decision-making in robot design and interaction strategies.

Keywords: SPE, Statistics, Robots

Sessão 1.5
Education

Moderadora: Paula Sarabando

O Ensino da Investigação Operacional na Voz dos Alunos: Dificuldades, Motivações e Propostas de Melhoria

Maria João Fernandes, Tiago Miguel, Manuel Reis, Paula Sarabando

Esta comunicação explora o ensino da Investigação Operacional (IO) a partir da perspetiva dos estudantes, procurando fomentar uma reflexão crítica e informada sobre as práticas pedagógicas nesta área. A metodologia integra o testemunho de uma antiga aluna — que partilha os principais desafios e fatores de motivação vivenciados — e a análise preliminar de um questionário atualmente em curso junto de estudantes do mesmo curso. O inquérito incide sobre as perceções dos alunos quanto aos conteúdos lecionados, estratégias de ensino utilizadas, dificuldades sentidas e relevância da IO para a sua formação académica e futura vida profissional. Esta abordagem visa valorizar a experiência discente como eixo central para a melhoria contínua do ensino da IO, promovendo um diálogo construtivo entre docentes e alunos. A comunicação culminará com um conjunto de propostas para tornar o ensino da IO mais dinâmico, envolvente e alinhado com os interesses e necessidades dos estudantes.

Keywords: Teaching, Education

Aprender Otimização a Jogar: Relato de uma Experiência com o Burrito Optimization Game

Lara Almeida, Jelise Cabral, Eliana Costa e Silva, Carla Lemos

Este trabalho apresenta, do ponto de vista de um grupo de estudantes da Licenciatura em Gestão Industrial e Logística da ESTG, P.PORTO, uma experiência de integração da gamificação no ensino da modelação matemática, através de um Trabalho Prático que tem como ponto de partida o Burrito Optimization Game, desenvolvido pela Gurobi (https://www.gurobi.com/burrito-optimization-game/). O trabalho foi desenvolvido em três etapas de complexidade crescente. A primeira consistiu na implementação e análise dos resultados do modelo binário apresentado no site da Gurobi. Nas fases seguintes, os grupos foram desafiados a modificar o modelo, introduzindo variáveis contínuas ou inteiras e restrições adicionais realistas, como limites de capacidade, locais obrigatórios ou proibidos e dependências condicionais entre decisões. Cada fase exigiu a implementação em software de otimização, reflexão crítica e comunicação clara dos resultados, culminando com uma apresentação e defesa oral. O enunciado aberto do trabalho permitiu aos estudantes explorar diferentes abordagens, propor variantes criativas e adaptar o modelo às suas próprias ideias, promovendo a autonomia, o pensamento crítico e o desenvolvimento de competências práticas em Investigação Operacional.

Acknowledgement: This work has been supported by national funds through FCT - Fundação para a Ciência e Tecnologia, under the projects UIDP/04728/2020 and UIDB/04728/2020.

Keywords: Teaching, Education, Gamification, Optimization

Hierarchical Analysis of Educational Strategies for Youth Financial Literacy Using the Analytic Hierarchy Process

Rogério Matias, Tiago Miguel, Manuel Reis, Paula Sarabando

Financial literacy is essential for the well-being and social inclusion of individuals of all ages, but its absence is particularly detrimental to young people. Portuguese students exhibit significant shortcomings in this area, largely due to the lack of structured instruction during compulsory education. This study applies the Analytic Hierarchy Process (AHP) to rank pedagogical strategies aimed at improving financial literacy among Portuguese youth. Four evaluation criteria were established - knowledge acquisition, motivation and engagement, accessibility and flexibility, and behavioral impact - alongside five pedagogical alternatives: in-person courses, online courses, digital content, books, and educational games/apps. Criterion weights were obtained via pairwise comparisons carried out with students using a survey, whereas the alternatives were assessed by a subject-matter expert. Findings indicate that behavioral impact is the most highly valued criterion, followed by knowledge acquisition. Among the alternatives, in-person courses were identified as the most effective, with online courses ranked second. Although digital tools scored highly on flexibility, their perceived effectiveness was lower. The study concludes that innovation in financial education should emphasize not only delivery format, but more critically, pedagogical quality and the capacity to drive behavioral change.

Keywords: MCDA, AHP, Education, Literacy

Sessão 2.1
Transportation

Moderadora: Beatriz Brito Oliveira

Enhancing carsharing pricing and operations through integrated choice models

Beatriz Brito Oliveira, Selin Ahipasaoglu

Balancing supply and demand in free-floating one-way carsharing systems is a critical operational challenge. We propose a novel approach integrating a logit model into a mixed integer linear programming framework to optimize short-term pricing and fleet relocation. Based on a binary logit model, demand modelling aggregates different trips under a unified utility model and improves estimation by incorporating information from similar trips. A categorizing approach is used to speed up the estimation process, where variables such as location and time are classified into a few categories based on shared attributes. The modelling framework adopts a dynamic structure where the binary logit model estimates demand using accumulated observations from past iterations at each decision point. This continuous learning environment allows for dynamic improvement in estimation and decision-making. At the core of the framework is a mathematical program that prescribes optimal levels of promotion and relocation. The framework then includes simulated market responses to the decisions, allowing real-time adjustments to balance supply and demand effectively. Computational experiments demonstrate the effectiveness of the proposed approach and highlight its potential for real-world applications. The continuous learning environment, combining demand modelling and operational decisions, opens avenues for future research in transportation systems.

Keywords: Carsharing, Pricing, Allocation, Logit, Optimization

Transit Network Design and Frequency Setting with elastic demand: a mixed-integer linear programming approach

João Pedro Lopes de Albuquerque, António Ramos Andrade, Marta Castilho Gomes

The main goal of this work is to develop a single-level mixed-integer linear programming framework for the Transit Network Design and Frequency Setting Problem that aims to capture demand by taking into consideration the travellers' preferences and activates or deactivates routes at a certain frequency accordingly, from a given pool of possible routes. This work was applied both to an illustrative example and to a case study of the existing bus and Bus Rapid Transit network in an area of the Barcelona Metropolitan Area, comprising 9 lines and 319 origin-destination pairs. For each origin-destination pair, each possible itinerary within the network is pre-computed and is compared against the best itinerary of each of the competing modes of transport, which are obtained using Google Maps. For each itinerary in the network its probability of being chosen based on its utility is computed, using a multinomial logit model, taking into consideration its access, waiting and travel time, cost and number of transfers. Its coefficients were calibrated using a Stated Preferences Survey. The goal is to maximize the total network demand by tuning the active routes and frequencies, activating the itineraries with the highest probability of being chosen, allocating most or a pre-determined percentage of the demand to them, constrained by number and capacities of buses. The formulation allows for different assumptions on traveller assignment, by tunning the percentage of travellers on the highest utility itinerary, and coverage, either forcing full coverage or not. The models are solved with the commercial software FICO Xpress within reasonable computational time and low optimality gaps.

Keywords: Transit Nework Design, Optimization, Logit

Integrating electric vehicles into urban car-sharing systems: addressing grid constraints and operational challenges for sustainable mobility

Sayeh Fooladi Mahani, Masoud Golalikhani, Beatriz Brito Oliveira

Urbanization is accelerating, creating challenges in transportation, energy use, and emissions. Car-sharing can lower private car ownership and greenhouse gas emissions, while electric vehicles (EVs) produce zero emissions and can use renewable energy. Combining EVs with car-sharing offers a sustainable transport solution. However, the rising electricity demand from widespread EV adoption may threaten grid stability and capacity, complicating their integration into car-sharing services. This study tackles the challenge of optimizing fleet operations while maintaining grid reliability. It presents a framework that addresses car-sharing operational issues and includes strategies to minimize charging impacts on distribution grids. Key strategies involve active management of EVs through coordination between distribution system operators and car-sharing companies to match charging with network demands and incorporating distributed generation, such as renewable energy and vehicle-to-grid technology. These strategies allow EVs to support the grid by considering the grid conditions while satisfying the needs of car-sharing systems. By modeling grid-aware EV car-sharing systems, this research provides actionable insights for improving system resilience and sustainability. The findings aim to support mobility operators and policymakers in developing efficient, scalable, and grid-compatible urban mobility solutions.

Keywords: Carsharing, Sustainability, Optimization, EV

Sessão 2.2
OR with Social Impact

Moderadora: Franklina Toledo

Social welfare in a design and distribution problem

Ana Bessa, Inês Duarte, Ana Barbosa-Póvoa, Tânia Pinto Varela, Cristóvão Silva, Samuel Moniz

While sustainability is a central concern in supply chain management, its social dimension remains widely underexplored. In the pharmaceutical industry, among various social sustainability standards, ensuring product availability and broad access to medicines is largely recognized as a key responsibility. To integrate social objectives while preserving economic efficiency, this study proposes a decision-support tool for the strategic and tactical planning of pharmaceutical supply chains. A bi-objective mixed-integer linear programming model is developed to simultaneously maximize net present value and ensure equitable product availability across different demand regions. The model incorporates decisions related to inventory holding, distribution, and design of manufacturers and warehouses. Realistic data from a vaccine distribution problem is used to validate the model. Preliminary findings highlight important trade-offs between economic performance and social equity. Managerial insights are provided to improve equity with minimal impact on costs.

Keywords: Multi-Objective, Optimization, Supply Chain, Sustainability, Health

Epidemiological Modelling of Misinformation with Optimal Intervention Strategies

Daniel Botelho, Teresa Monteiro, Senhorinha Teixeira

Fake news poses an increasingly critical threat to societal stability by shaping opinions, eroding institutional trust and deepening social polarisation. Every day, misleading content circulates across digital platforms with real consequences such as political manipulation.
Due to the resemblance of the spread of fake news with the transmission of infectious diseases, epidemiological frameworks, specifically the Susceptible-Infected-Recovered (SIR) model, are considered well suited to analyse its dynamics. In this work optimal control theory is applied in order to curb the propagation of false information. The cost functional is defined by two weights: one that penalises the overall number of users who have been mislead - to capture the social cost of the fake news - and another to quantify the economic and/or operational cost associated with the control action itself (e.g. content moderation).
SIR parameters (infection and recovery rates) are estimated by fitting the model to real-world fake-news data. By combining least-squares technique and a derivative-free optimisation algorithm in MATLAB, the optimal parameters that best describe the specific false information spread are obtained. The Forward-Backward-Sweep Method (FBSM) is then applied to compute the optimal control strategy, or intervention, aimed at minimising the number of misinformed individuals while balancing social harm against intervention cost.

Keywords: Optimal Control, Fake-News, Multi-Objective, Epidemiology

Centro de Troca de Alimentos: um enfoque social

Franklina Toledo, Giulia Pereira Mendes

Apesar do compromisso do Brasil em atingir a Fome Zero (2o. Objetivo de Desenvolvimento Sustentável da ONU), o país retornou ao mapa da fome em 2022. Nas cidades brasileiras, é muito comum termos várias instituições civis e religiosas que distribuem cestas de alimentos para famílias em situação de vulnerabilidade. Uma cesta de alimentos, chamada de cesta básica, contém um conjunto de alimentos destinados a ajudar uma família por um mês. Estas instituições dependem de doações, logo podem receber grandes quantidades de certos alimentos e pouca de outros. Portanto, muitas vezes não conseguem obter todos os ingredientes em quantidade suficiente para montar o número de cestas necessárias para as famílias atendidas. Nesse caso, a instituição precisa buscar outros doadores. Um desses doadores é o Fundo Social de Solidariedade (FSS) do município, que devido ao orçamento limitado, nem sempre consegue comprar todos os alimentos requisitados por todas as instituições. Neste trabalho, estudamos a proposta de um centro de troca social onde as instituições deixam os alimentos que têm em excesso e retiram os precisam. Propusemos um modelo matemático para representar o problema. Experimentos computacionais baseados em instâncias artificiais foram realizados. Apoio financeiro FAPESP 2024/04929-9 e CNPq 309161/2022-3.

Keywords: Optimization, Solidarity, Food

Sessão 2.3
Scheduling

Moderador: Gonçalo Figueira

Learning Dispatching Rules for a Large-Scale Scheduling Problem of a Maintenance Provider

Nuno André Azevedo Marques, Gonçalo Figueira, Luís Guardão, Luís Guimarães

Nowadays, companies desire to offer customised products and services to their customers. At the same time, they want to address customers' requests as fast as possible. In addition, operations are often subject to high uncertainty and frequent disruptions, such as urgent order arrivals, resource unavailability, and product defects. Under these conditions, companies need to schedule tasks quickly, often in real-time, and therefore use dispatching rules. However, the performance of those rules depends on the objectives, settings, and conditions for which they were designed. Generating rules by hand for the several possibilities is burdensome. Consequently, using artificial intelligence to find new dispatching rules became common. This work uses genetic programming to find new rules in a large-scale scheduling problem of a real-world maintenance provider. This problem was modelled as a Dynamic Resource-Constrained Multi-Project Scheduling Problem. It includes several sources of uncertainty, such as unexpected arrivals, uncertain processing times and unplanned work. Genetic programming rendered dispatching rules around 10% better tardiness-wise than existing ones from the literature while maintaining a compact size.

Keywords: Scheduling, Maintenance, Optimization, Genetic Algorithm

Learning to schedule from demonstrations: What we lose by only imitating the best?

Alexandre Jesus, Arthur Corrêa, Samuel Moniz, Cristóvão Silva

Early success of Deep Reinforcement Learning (DRL) was rooted in arcade and board games, where expert behavior could be readily captured from top players. In these settings, demonstrations were used to bootstrap learning and accelerate policy convergence. In contrast, in combinatorial optimization problems, such as the Flexible Job-shop Scheduling Problem (FJSP), optimal demonstrations are costly to obtain. In this work, we build on a state-of-the-art DRL framework to investigate how the quality and diversity of demonstrations from FJSP solutions affect learning dynamics and policy generalization. We argue that representativity of the action space is more beneficial for pretraining than strict optimality. To that end, we consider an efficient Constraint Programming (CP) method and several composite heuristic rules as candidate experts. These were evaluated based on the final policy performance, the generalization to unseen instances, and the time required to gather expert FJSP solutions. Preliminary results show that agents pre-trained with diverse sub-optimal demonstrations converge faster to near-optimal policies than those trained solely on solver-based solutions. Moreover, combining CP and heuristic demonstrations leads to superior robustness to unseen instances. These findings suggest that diversity and representativeness in expert behavior may be more critical than optimality alone.

Keywords: Machine Learning, Heuristic, Constraint Programming, Scheduling

Efficient nesting via Fast Fourier Transforms to solve the production scheduling problem in Additive Manufacturing

Paulo Nascimento, Samuel Moniz, Cristóvão Silva

The interdependence of nesting and production scheduling problems in Additive Manufacturing (AM) systems poses a significant computational challenge when considering traditional optimization methods. This work addresses the AM scheduling problem (AMSP), with a particular focus on the nesting component, which remains the major computational bottleneck in existing approaches. Current nesting methods frequently rely on complex and computationally intensive preprocessing and struggle to scale efficiently or handle multiple part rotations. Building on an in-depth review of geometric tools for handling part geometry and no-overlap constraints, we propose a nesting framework that builds on raster-based representations and exploits the Convolution Theorem by employing Fast Fourier Transforms on modern computing hardware to quickly identify feasible part placements. Contrary to the expectations, results show that finer raster resolutions and a predefined number of rotations do not significantly impact run time, highlighting the scalability and efficiency of the method. This nesting framework is integrated into a Biased Random-Key Genetic Algorithm (BRKGA) to address the AMSP in a unified manner. Initial experiments on benchmark datasets showcase the competitiveness of our approach compared to state-of-the-art methods, offering a promising path toward scalable and efficient AM scheduling.

Keywords: Scheduling, Manufacturing, Nesting, Genetic Algorithm

Sessão 2.4
Bilevel optimization

Moderadora: Maria João Alves

A bilevel approach to enhance flexibility in retailer-supplier agreements for perishable products

Maria Santos, Pedro Amorim, Margarida Carvalho, Sara Martins

One key condition in these retailer-supplier agreements is the Minimum Life On Receipt (MLOR) rule, which defines the maximum product age acceptable by the retailer to pay the full price. In this study, we propose a model that helps negotiate the retailer-supplier agreement's conditions to make them more flexible. Specifically, we define the share of orders that may be accepted by the retailer beyond the MLOR at a discount. We formulate the problem as a bilevel program considering the individual objectives of the retailer (leader) and the supplier (follower), as well as a consumer demand driven by prices and product freshness. The bilevel problem is solved with a reformulation-and-decomposition algorithm. We compare the supply chain benefits of solving the bilevel program with those of optimizing the retailer's and supplier's objectives jointly in a centralized approach. We also compare it with the standard contracted terms, in which products are returned if the supplier fails to comply with the MLOR. Our results highlight the advantages of adopting these flexible agreements, with an average increase of profits of up to 4% for the retailer and up to 13% for the supplier. We also provide suggestions on how to design a new clause in these agreements according to consumer demand variability and the retailer's order frequency.

Keywords: Retail, Bilevel, Optimization, Negotiation

Uma abordagem de otimização em dois níveis para a agregação da flexibilidade no consumo de energia elétrica

Maria João Alves, Carlos Henggeler Antunes, Ana Soares, Inês Soares

A flexibilidade é fundamental para a gestão de sistemas de energia, tendo como objetivo incentivar a alteração dos padrões de consumo de eletricidade face à crescente produção renovável variável. Os agregadores desempenham um papel importante, recolhendo a flexibilidade dos consumidores/produtores, que pode depois ser transacionada em mercados, criando benefícios económicos e operacionais para todas as partes interessadas. A interação agregador-consumidores pode ser modelada como um problema de otimização em dois níveis de multi-seguidor. O agregador, no nível superior, estabelece incentivos financeiros, enquanto os consumidores, no nível inferior, otimizam a utilização de energia em resposta a estes incentivos e preços da eletricidade, tendo em conta preferências de conforto. Para resolver este problema, propomos uma abordagem híbrida que combina otimização por enxame de partículas para o problema de nível superior com um solver exato para o problema de nível inferior de programação inteira-mista. Apresentam-se experiências computacionais para um conjunto de consumidores residenciais típicos, considerando diferentes eletrodomésticos, veículo elétrico, baterias e microgeração.

Keywords: Bilevel, Optimization, Heuristics, Energy, Electricity

A bilevel approach to hyperparameter optimization for a support vector machine classifier

Ana Januário, Maria João Alves, Carlos Henggeler Antunes

In this work, a hyperparameter (kernel and C) optimization model for a support vector machine (SVM) classifier applied to handwritten digit recognition is presented. The kernel determines how the data is transformed and separated, which directly affects the model's ability to capture complex patterns. The regularization parameter controls the balance between fitting the training data and maintaining the model's ability to generalize to new data. We developed a bilevel optimization framework where the lower level minimizes the SVM loss using a deterministic algorithm (L-BFGS-B), and the upper level searches for the optimal hyperparameter values using a particle swarm optimization metaheuristic. Cross-validation with three folds is used to evaluate model performance, reporting mean accuracy and standard deviation. We compare the bilevel approach with other automated hyperparameter tuning methods, including grid search, random search, Hyperband, and Bayesian optimization. Preliminary results suggest that the bilevel framework can achieve superior classification performance, although the tradeoff between the quality of results and the computational effort should be further investigated. These experiments highlight the potential of bilevel optimization for tuning hyperparameters in complex machine learning models. We acknowledge the support of the HarmonicAI project, which contributed to the development of this work.

Keywords: Machine Learning, Bilevel, Optimization, Heuristic, SVM

Sessão 2.5
AI and OR in healthcare

Moderadora: Ana Sara Costa Domingues

Predicting hospital efficiency through integrated Data Envelopment Analysis and machine learning

Mariana Oliveira, Miguel Pereira, José Figueira

Health systems are under growing pressure due to resource constraints and increasing demand. Measuring hospital efficiency is therefore crucial to support effective management and evidence-based policymaking. This study introduces an innovative framework that combines Data Envelopment Analysis (DEA) with machine learning (ML) techniques to assess and predict the efficiency of Portuguese public hospitals. Efficiency scores were obtained using the Super Efficiency Slacks-Based Measure DEA model, applied to a ten-year dataset from 2014 to 2023. Results indicate that 76.82% of hospital units operated inefficiently, with marked disparities across regions, particularly in the south and interior areas. To enhance the model's predictive capacity, ten ML algorithms were evaluated, with XGBoost achieving the highest accuracy. The integrated SuperSBM-DEA and XGBoost model enables the simulation of improvement scenarios for underperforming hospitals and anticipates the efficiency impact of managerial decisions. Beyond its predictive performance, the framework offers actionable insights and holds strong potential for integration into national healthcare policy. The findings suggest the feasibility of a centralised, data-driven system for dynamic resource allocation, contributing to a more equitable and efficient provision of care across regions.

Keywords: DEA, Machine Learning, Health

Public hospitals five-star rating considering interactions in pairs of access and quality criteria

Beatriz Cagigal Gregório, Miguel Pereira, Ana Sara Costa Domingues

In pursuit of a more sustainable future, populations and economies need to be protected by stronger and more resilient health systems. Their complexity requests adequate assessment frameworks for improving the access and quality of their services. Due to the multidimensional nature of health systems, this study presents a collaborative multi-criteria decision-aiding framework to assess the performance and classify public hospitals' performance in terms of service quality and access using a five-star rating system. Existent studies in this area usually assume criteria independence, besides modelling criteria interactions could be more realistic. However, this notion has not yet been entirely understood, nor have there been any applications to the health sector. Thus, our framework innovates by modelling interactions in some pairs of criteria, identified by the decision-maker, using the ELECTRE TRI-nC method. We obtained a five-star rating for 26 Portuguese public hospitals. The majority hospitals were assigned to '2 stars' ('poor') and '3 stars' ('average') categories over the considered 4-year period. We conclude that assuming criteria dependence reveals more realistic results in comparison to a criteria independence assumption. We observed that the number of doctors and nurses does not influence the assignment of the hospitals to the categories. Robustness analyses evidence the framework's credibility.

Keywords: MCDA, Health, Hospitals, Rating

Explainable Machine Learning For Healthcare Cost Optimization: A Time-Driven Approach

Salomé Azevedo, Maria Isabel Gomes, Dulce Loureiro

Efficient cost and resource allocation in healthcare is essential for the sustainability of hospital operations and patient-centered initiatives. However, this can be a complex issue due to the extensive scope of work and the difficulty in maintaining economic models designed for these evaluations. In recent years, machine learning (ML) has been increasingly adopted to support healthcare decision-making, but despite its predictive power, a major limitation remains: the lack of interpretability in many models, which hinders trust and usability by medical personnel.

In this study, we use the electronic medical records of 2800 cardiothoracic surgery patients of Santa Marta's Hospital and propose a novel approach that integrates ML with mathematical optimization to provide interpretable insights for healthcare cost analysis. Our methodology incorporates set covers within a clustering algorithm to identify representative patient cohorts, addressing the explainability gap in current ML approaches. Subsequently, we apply the Time-Driven Activity-Based Costing model to estimate the cost of each patient type by mapping clinical activities to time-based resource consumption. By combining optimization techniques with interpretable machine learning, our approach provides a transparent framework for healthcare cost analysis. This supports more informed decision-making, aligns with the growing demand for explainable ML in healthcare, and enhances communication between technical and clinical stakeholders.

Keywords: Machine Learning, Optimization, Health, Costing

Sessão 3.1
Optimization in networks

Moderadora: Maria Cândida Mourão

Inspecting Electric Lines with Drones

Maria Cândida Mourão, Raquel Bernardino, Cristina Requejo, Leonor Santiago Pinto

This study addresses the routing for the inspection of electric lines with drones in Portugal, managed by EDP Labelec, the partner company in this project. There is a set of electrical lines that need to be inspected and a set of points where the drone operator can stop managing the drone for inspecting those lines. The objective is to determine an inspection plan — that is, the points where the drone operator stops and the routes performed by the drone — to inspect all the service lines, that minimizes the inspection time. This problem is modeled as an Extended Capacitated Arc Routing Problem (ECARP). The CARP is known to be NP-hard, as is this ECARP since it generalizes the CARP. The developed model is solved using CPLEX on smaller real instances generated using a GIS (Geographic Information System) available at the EDP Labelec. The quality of the solutions generated is assessed by the total inspection time, as well as feedback from the EDP Labelec team. This team evaluates the practical adequacy of the solutions, a crucial aspect for trips that need to be accepted by practitioners. Computational analysis will provide new insights for the development of new methodology to solve larger instances that feat the dimensions of the real ones. Acknowledgments: research supported by Portuguese National Funding from FCT - Fundação para a Ciência e a Tecnologia, under project ISEG-Research - UID/06522/2023

Keywords: Routing, Drones, Optimization, Capacitated Arc Routing, GIS

Optimização da supressão de incêndios florestais

Filipe Alvelos, André Mendes

Desde o final da década de 1950 que a Investigação Operacional tem contribuido para a gestão de incêndios florestais. Em anos recentes, têm sido propostas diversas aborgadens para o problema de supressão que, genericamente, consiste em decidir onde colocar os meios disponíveis para atacar o incêndio da forma mais consequente. Nesta apresentação discutem-se abordagens baseadas em programação inteira mista para lidar com esse problema considerando diversas variantes: ataque inicial, ataque estendido directo e indirecto, meios terrestres e aéreos. A modelação baseia-se na definição de uma rede relativa à propagação do incêndio e de outras redes para movimentação e ataque dos meios. Um mesmo modelo integra as diversas redes e as decisões a elas associadas. Apresentam-se resultados de experiências computacionais e discutem-se direcções para reforçar a aplicabilidade das abordagens propostas.

Keywords: Fire, Forest, Optimization, Networks

Network-Based Resource Planning for Wildfire Management

Elsa Silva, Filipe Pereira Alvelos

This work addresses the design of networks to support wildfire preparedness activities, namely surveillance, detection, and suppression. The problem is defined over a graph where nodes represent potential locations for positioning resources (e.g., watchtowers or firefighting crews), and arcs denote direct connections (e.g., roads) between these locations. We propose a mixed-integer programming model that integrates two decision layers: covering (selecting resource positions to ensure area coverage) and network design (selecting arcs to define the network structure). The model supports different topological configurations, including spanning trees, shortest-path trees, and Hamiltonian circuits. Different objectives are considered, such as maximizing coverage and minimizing the total network length. Computational experiments are conducted on a real-world landscape to evaluate the performance and flexibility of the proposed approach. The results highlight the trade-offs between coverage and network compactness and show how the model can adapt to different planning priorities and operational constraints. This integrated formulation offers a general and extensible framework for designing spatially distributed wildfire preparedness systems, with potential applicability to other emergency response planning contexts.

Keywords: Fire, Forest, Optimization, Networks

Patrolling Routes for the Amazonas River Navigation System

André Bergsten Mendes, Miguel Cezar Santoro, Laura Bahiense, Elcio Ribeiro

The Amazon River and its tributaries form an extensive and complex network exceeding 10,000 km, comprising several significant tributaries. These rivers are crucial for connectivity, facilitating trade and commerce, and providing access to services for local communities. Patrolling these waterways is essential to curb illegal activities, protect biodiversity, and safeguard local communities. The aim of this research is to develop patrolling routes for the Amazon River navigation system, conceptualized as a variation of the periodic arc routing problem. This study considers factors such as the navigation time span, which can make some routes exceptionally long, seasonal variations (floods and droughts) that restrict route availability, and varying visitation frequencies for each river stretch. This issue is also approached as a profit-collection problem, with benefits derived from the arcs monitored and secured. Different Mixed Integer Programming (MIP) formulations are proposed and evaluated, taking into account decisions regarding fleet size and base positioning. Results are obtained using real data.

Keywords: Routing, Optimization, Networks, Rivers

Sessão 3.2
OR in waste management

Moderadora: Tania Rodrigues Pereira Ramos

Strategic decisions in the valorization of subproducts

Simone Lima, Maria João Santos

The recovery of food waste is a trend in the current context of sustainability, circular economy, and waste reduction. For example, it is possible to use peels, seeds, and non-standard fruit to produce new products such as jams, teas, flour, or transform them into animal feed, biofertilizers, or cosmetics. The literature on food waste and losses along the food supply chain is vast, but quantitative studies that support the decision of which are the best valorization solutions for food waste and losses are limited. Based on this literature gap, the main objective of this work is to identify efficient matches between food subproducts and the most suitable recovery strategies. Using multi-criteria decision models, we will analyze viable strategies capable of producing value while guaranteeing relevant logistical constraints. Developing valorization strategies in environmental, operational, and economic terms can contribute directly to reducing food waste and food losses along the production and supply chains.

Keywords: Multi-Criteria, Food Waste, Circular Economy, Supply Chain, Sustainability

From Blind Collection to Smart Routing: A Data-Driven Analysis of Waste Collection in Figueira da Foz

Ygor Acácio, Tania Rodrigues Pereira Ramos

This study analyzes the waste collection operations of the municipality of Figueira da Foz, Portugal, using real operational data from February 2020 to April 2024. The objective is to evaluate and optimize the current system through four distinct scenarios. First, we establish a baseline by examining the existing system, which operates on fixed schedules and routes - a method commonly referred to as blind collection. In the second scenario, we automate collection frequency and routing by clustering containers according to their historical filling patterns, aiming to reduce inefficiencies and unnecessary trips. The third scenario simulates a fully sensorized system, where real-time data from all containers enables a highly dynamic and responsive routing process. Finally, we explore a partially sensorized network, where only selected containers are equipped with sensors. The data from these containers is used to infer the behavior of similar, non-sensorized containers within the same cluster. For each scenario, we solve a Vehicle Routing Problem with Profits (VRPP) to optimize collection routes and maximize efficiency. The results demonstrate that partial sensorization, combined with behavioral clustering, can significantly enhance operational performance and reduce costs, even without full sensor coverage.

Keywords: Routing, Optimization, Simulation, Waste, Sensors

Stochastic Waste Collection Routing with Profit: A two-stage framework

Héctor Fabio Bonilla Bonilla Londoño, Ana Paula Barbosa Póvoa, Tania Rodrigues Pereira Ramos

This study addresses the Waste Collection Vehicle Routing Problem with Profit (WCVRP) while considering uncertainty in bin fill levels a critical challenge for municipalities and waste management providers aiming to enhance service efficiency. In real-world conditions, bins fill levels fluctuate unpredictably, leading to inefficient routing, unnecessary trips, or uncollected waste. To tackle these issues, we propose a Two-Stage WCVRP that incorporates uncertainty through a scenario-based approach. Scenarios are generated from residuals of predictive models, capturing realistic variations in bins waste usage.
The model employs a single recourse strategy: an overflow penalty is incurred when containers exceed their capacity and waste remains uncollected. This approach avoids the need for vehicle return trips and reflects practical constraints in urban collection systems. The objective is to maximize profits by balancing collection revenues, travel costs, and penalty costs. Formulated as a variant of the Capacitated Vehicle Routing Problem with Profit (CVRPP), the model performance is evaluated using indicators such as total profit, total distance traveled, and total waste collected.
Stochastic metrics, including the Expected Value of Perfect Information (EVPI) and the Value of the Stochastic Solution (VSS), are also calculated to assess the value of explicitly modeling uncertainty. A preliminary case study in Rio Maior, Portugal,demonstrates the applicability of the developed approach.

Keywords: Routing, Optimization, Stochastic, Waste

Nova abordagem para a otimização da gestão de resíduos de construção e demolição (com componente temporal)

Marta Castilho Gomes, Fernando Braga, Joaquim Duque

Os impactos causados pelos resíduos de construção e demolição (RCD) podem ser elevados caso não se efetue uma gestão eficaz dos mesmos. Em consequência, as preocupações relacionadas com esta gestão têm aumentado nos últimos anos, estimulando a elaboração de estudos sobre o assunto. Este trabalho deu continuidade aos trabalhos de Correia (2013) e Andrade (2015), que desenvolveram uma nova abordagem para o planeamento de uma rede de reciclagem de RCD, utilizando um modelo de programação linear inteira mista visando a minimização de custos. Neste trabalho foi adicionada uma componente temporal à formulação matemática, possibilitando a modelação dos fluxos de materiais entre os diversos processos para cada um dos períodos do horizonte temporal considerado. O modelo foi validado utilizando um conjunto de dados reduzido, sendo consideradas apenas 10 freguesias e, em seguida, foi aplicado às 211 freguesias que compõem a Área Metropolitana de Lisboa, com a geração de múltiplos cenários e um análise de sensibilidade aos parâmetros mais relevantes. Embora tenha sido aplicado a nível regional, a formulação é genérica ao ponto de poder ser utilizada a nível nacional. Os resultados obtidos indicam que, do ponto de vista económico, é mais viável depositar os RCD em aterro do que reciclar. Além disso, é possível concluir que o custo de deposição em aterro dos resíduos possui elevada influência na quantidade de RCD reciclados.

Keywords: Optimization, Waste, Recycling, Construction

Sessão 3.3
Retail and sales

Moderador: Bernardo Almada-Lobo

The introduction of online operations to brick-and-mortar grocery stores and its impact on spoilage

Pedro Amorim, Sara Martins

Omnichannel grocery retailers often use stores to fulfill online orders for a variety of reasons (e.g., faster deliveries, labor availability). This strategy influences inventory management, particularly the spoilage ratio (defined as the ratio of loss to sales) in two opposing ways. Fulfilling online orders has the potential to increase the sales-to-stock ratio thereby improving turnover and, consequently, the spoilage ratio. However, the last-expired-first-out picking policies used by store employees to serve online customers may generate higher levels of spoilage in the store. Using granular data from a grocery retailer, we study the impact that introducing online fulfillment to existing stores has on spoilage. Our empirical methods include a staggered difference-in-difference approach to account for the way in which online fulfillment was adopted throughout the chain. We find the spoilage ratio to increase, on average, with the introduction of online fulfillment at brick-and-mortar stores. However, substantial heterogeneity in this increase exists across product categories and stores. We exploit this heterogeneity to understand more about the dynamics of online order fulfillment and to caution retailers about several unforeseen performance impacts of online operations.

Keywords: Inventory, Retail, Ecommerce

Forecast-Driven Sales and Operations Planning for Balancing Supply and Demand in the Rice Industry

Francisco Monteiro, Diogo Bento, Joana Hora, Henrique Neto, Daniel Pereira, Pedro Schuller

Industrial companies often struggle to balance supply and demand, leading to excess inventory, stockouts, and reactive decision-making. This case study examines a rice company that lacked formal demand planning and relied on siloed, unsophisticated forecasts. The main research goal was to improve decision-making, operational efficiency, and strategic alignment in the company. This was pursued by identifying deficiencies in demand planning and defining solutions to surpass them. Data were gathered from the company's database and through interviews across multiple organizational levels. Analysis of the current situation lead to implementing a Sales & Operations Planning (S&OP) process underpinned by a forecasting pipeline. The proposed S&OP process entails monthly compilation of demand and market data, forecast validation, and a mid-month meeting outputting a consensus sales plan. The forecasting pipeline begins with baseline-driven forecasts, which undergo optimal hierarchical reconciliation and weekly disaggregation using historical proportions. Demand spikes—stemming from promotions and non-Gregorian seasonality—are modeled respectively with random forests and exponential smoothing. Finally, on-hand orders are incorporated to further refine forecasts. The S&OP cycle enhances cross-functional alignment and proactive decision-making. The forecasting pipeline markedly outperforms the prior budget-based forecasts. Future work could introduce two-fold forecasting for intermittent series, production strategy optimization and portfolio rationalization.

Keywords: Sales & Operations Planning, Forecasting, Agriculture (Rice)

Balancing Fulfillment Costs with Vendor Goals: Optimizing Order Allocation in Online Marketplaces with Reinforcement Learning

Sérgio Castro, Bernardo Almada-Lobo, Gonçalo Figueira, Willem van Jaarsveld

Online marketplaces provide a platform that connects suppliers with customers, allowing vendors to sell their products to a broader audience. To streamline customer experience, some marketplaces allocate a set of fulfillment vendors and stockpoints at the moment a customer is placing an order in the platform. This order allocation decision impacts not only fulfillment costs and customer satisfaction but also sales volume received by suppliers, directly impacting supplier retention on the platform. We introduce the Multi-Item Order Fulfillment Problem in Online Marketplaces, which considers suppliers' perspective by incorporating sales targets over a selling season. Reinforcement Learning is applied to the problem by means of the Deep Controlled Learning algorithm, which hybridizes Approximate Policy Iteration with Supervised Learning. As a benchmark, two families of solution methods are considered: various myopic rule-based policies, popular in practice, and two randomized policies with attractive asymptotic properties. We compare these policies on real-world-based instances tailored based on past interactions with an online marketplace. We find that our approach is superior when demand per item is relatively low, while achieving balanced outcomes on the multiple perspectives (cost, supplier and customer satisfaction).

Keywords: Ecommerce, Retail, Order Fulfillment Problem, Machine Learning

Integrating perishables' short life into assortment optimization

Pedro Amorim, Dorothee Honhon, Sara Martins, Maria João Santos, Mariana Sousa

Retailers' product mix selection is a key determinant of market share, profitability, and long-term success. While a broader assortment increases the likelihood of meeting diverse customer preferences, it raises inventory-related costs and stockout risks, ultimately affecting operational performance and customer loyalty. This challenge is amplified for perishable goods, where limited shelf life narrows the selling window and increases spoilage risks. Despite extensive research on assortment optimization, existing models fail to integrate perishability dynamics. The few studies that consider shelf life treat it as a constraint rather than a factor influencing substitution patterns and retailers' profitability. However, ignoring perishability can lead to suboptimal product selection, excessive waste, and lost revenue. This study introduces an assortment optimization framework that integrates remaining shelf life into decision-making. Unlike conventional models, it accounts for shelf-life-sensitive demand and substitution effects, helping retailers balance waste reduction, profitability, and service levels. Using historical data from a European grocery retailer, we assess the framework's effectiveness and quantify the profitability and waste gap. Our findings highlight the importance of shelf life in assortment planning, introduce new heuristics for perishable product selection, and offer actionable insights to improve retail efficiency, sustainability and financial performance.

Keywords: Assortment, Retail, Heuristics, Optimization

Sessão 3.4
Artificial Intelligence and OR

Moderador: Luís Guimarães

Diferenciação de Espécies Bacterianas com Inteligência Artificial a partir de Compostos Orgânicos Voláteis

António Prata Cardoso, Felipe Yamada, Flávia Barbosa, Luís Guimarães

As infeções associadas aos cuidados de saúde representam uma ameaça significativa à saúde pública, agravada pela sua resistência antimicrobiana. Métodos tradicionais de deteção apresentam várias limitações, incluindo baixa sensibilidade e custos elevados. Uma alternativa promissora é a deteção de compostos orgânicos voláteis (VOCs) emitidos por bactérias, que atuam como uma "impressão digital" única. Este estudo recorre ao Few-Shot Learning (FSL), uma abordagem de Machine Learning eficaz em contextos com poucos dados rotulados, para analisar imagens geradas a partir de padrões distintos de corrente de ionização dos VOCs libertados. Esses padrões são obtidos através de um método de deteção bacteriana com um detetor fotoionizante multiplexado por comprimento de onda (PID). Para extrair características das imagens, utiliza-se uma rede neuronal convolucional (CNN) pré-treinada, especificamente a ResNet-18. Em seguida, aplica-se a Prototypical Networks para classificar as espécies bacterianas, comparando amostras com protótipos representativos de cada classe. Esta abordagem baseada em inteligência artificial oferece uma solução promissora para a deteção bacteriana em tempo real, especialmente no diagnóstico clínico e no controlo de infeções, onde a escassez de dados representa um desafio significativo.

Keywords: Machine Learning, Health, IA

Reframing Signal Drift: An AI-Based Approach for Functionalized Graphene Sensors

Felipe Yamada, Flávia Barbosa, António Prata Cardoso, Luís Guimarães

Graphene field-effect transistors (GFETs) are powerful tools for detecting a variety of biological and chemical substances, including ions, glucose, DNA, and proteins, due to their exceptional sensitivity to electric fields. Although non-functionalized GFETs have performed well, especially when combined with Artificial Intelligence (AI), this study centers on the use of functionalized GFETs. These devices incorporate molecular probes that selectively bind to target DNA sequences on the graphene surface, enabling highly specific detection at extremely low concentrations. Despite their enhanced selectivity, functionalized GFETs remain susceptible to interference and signal drift. This study explores their application in detecting bacterial DNA and evaluates their performance under realistic conditions. A major limitation of conventional detection methods is the tendency to simplify analysis by focusing only on limited regions of the sensor's output, discarding complex signal segments that may hold valuable information. Rather than aiming to generalize across devices, the primary objective of this study is to investigate whether the typically discarded regions of GFET signal data contain meaningful patterns. By applying Deep Learning to the complete "V"-shaped transfer curves, this approach reveals insights into the operational behavior of functionalized GFETs, improving data utilization and informing the design of more robust biosensing systems.

Keywords: Machine Learning, Chemistry, IA

How integration of generative AI and optimization methods can accelerate product design and manufacturing process development?

Antonio Forno, John Hart, Samuel Moniz, Haden Quinlan

Current methods in product development and industrialization are rigid, resource-intensive, and reliant on expert intuition. Integrating Artificial Intelligence (AI), particularly Generative AI (GenAI), with combinatorial optimization presents significant potential to address these challenges. Such integration can enable data-driven, automated decision-making across the product lifecycle—from early-stage design and optimization to scale-up, transitioning a product or process from the development stage into full-scale manufacturing. Despite this potential, effective application in engineering domains requires the incorporation of domain-specific knowledge, the handling of complex constraints, and the delivery of actionable outcomes. This work presents a preliminary analysis of how GenAI can be combined with optimization techniques to support complex engineering design and industrialization tasks. It includes a critical review of integration strategies, such as embedding engineering constraints, leveraging expert input to guide AI exploration, and translating AI-generated solutions into accessible and effective decisions. We conclude with a discussion on the role of these technologies in engineering workflows, evaluating their suitability for full automation versus their use as co-pilot systems in hybrid human–AI teams.

Keywords: AI, Combinatorial, Optimization, Manufacturing

Forecasting UK Socioeconomic Indicators under Political Uncertainty: Classical vs Deep Learning Approaches

João F. Botas, Diogo A. Freitas, Ricardo A. Galvão, Miguel G. Pereira, Filipe R. Ramos

Abstract The growing uncertainty of the international economic and political landscape, accentuated by phenomena such as Brexit and the pandemic, highlights the importance of robust and interpretable decision-support tools. In this environment, operational research (OR) is crucial for designing sustainable and innovative solutions for both society and businesses. This study contributes to this goal by applying advanced time series modelling techniques to inform evidence-based strategic decisions in socio-economic contexts. Time series data on UK job vacancies and 10-year bond yields are analysed alongside the political uncertainty index to explore forecast accuracy and causal relationships. A wide range of forecasting models were evaluated, including classical models (ARIMA and ETS) and deep learning architectures (GRU, LSTM, CNN and a hybrid approach). Performance was assessed across multiple forecast horizons using walk-forward validation and error metrics (sMAPE and R^2). The results demonstrate that classical models outperform deep learning models in the short term, while GRUs demonstrate superior performance in the long term. Granger causality tests confirmed statistically significant relationships between political uncertainty and the economic indicators studied. These findings emphasise the value of integrating OR and AI-based modelling to make resilient and sustainable decisions in uncertain situations and provide valuable insights for designing policies and planning strategies in dynamic economic environments. Keywords: Socioeconomic Indicators; Political Uncertainty; Time Series Forecasting; ARIMA and ETS Models; Deep Learning Models; Causal Inference

Keywords: Forecasting, Uncertainty, Machine Learning, Socioeconomic Indicators

Sessão 3.5
Data Envelopment Analysis

Moderador: Miguel Alves Pereira

Avaliação da Eficiência das Universidades Europeias

Rodrigo Cardoso, Maria Gouveia, Carla Henriques

A pandemia de COVID-19 provocou mudanças significativas no ensino superior, obrigando as universidades a adaptarem-se rapidamente ao ensino remoto e à gestão eficiente de recursos. A crise colocou à prova a capacidade das instituições de rever processos, otimizar o uso de recursos e manter a qualidade do ensino e da investigação. Este trabalho tem como objetivo avaliar a eficiência do ensino superior europeu durante a pandemia, identificando ineficiências nas universidades e analisando o impacto da crise. A amostra inclui 30 universidades europeias, nos anos de 2019 e 2020, considerando duas perspetivas: operacional e financeira. A metodologia utilizada foi a Value-Based Data Envelopment Analysis, complementada com o Índice de Produtividade Total dos Fatores, que permite medir variações de produtividade ao longo do tempo. Os resultados sugerem que a pandemia poderá ter tido um impacto positivo na eficiência universitária. Em 2019, 16 universidades foram consideradas eficientes do ponto de vista operacional, aumentando para 19 em 2020. Na vertente financeira, o número passou de 17 para 18. A eficiência operacional associa-se à redução de doutoramentos e ao aumento de licenciados e mestres, enquanto a eficiência financeira relaciona-se com a minimização de despesas de capital.

Keywords: DEA, MCDA, Ensino

Inteligência Artificial e Sustentabilidade no Emprego: Uma Avaliação de Eficiência na União Europeia

Artur Rodrigues, Maria Gouveia, Carla Henriques

O trabalho tem como objetivo estudar o impacto da Inteligência Artificial (IA) no mercado de trabalho europeu, com ênfase no Objetivo de Desenvolvimento Sustentável 8 (ODS 8), que visa promover o emprego pleno e produtivo. Utilizando o modelo Window Value-Based Data Envelopment Analysis, foi avaliada a eficiência de 20 países da União Europeia no uso de recursos relacionados com a IA — publicações científicas, migração de talentos, investimento privado e número de especialistas em Tecnologias de Informação e Comunicação — no período de 2019 a 2023. Os resultados indicam que países como Alemanha e França apresentam desempenho eficiente e consistente, enquanto Áustria, Bélgica e Portugal enfrentam ineficiências persistentes. Observa-se ainda uma concentração de talentos no Norte da Europa e a contínua saída de profissionais qualificados do Leste Europeu. A pandemia impulsionou a adoção de IA, mas acentuou desigualdades na preparação digital entre os países. A avaliação foi complementada por hierarchical clustering, que identificou três grupos distintos: Cluster 1, com tendência negativa persistente; Cluster 2, com ligeira recuperação; e Cluster 3, com desempenho estável e crescente. A análise por cluster revela padrões distintos de eficiência ao longo do tempo. Conclui-se que o avanço da IA exige políticas públicas diferenciadas, com foco na requalificação profissional, na distribuição equitativa de talentos e na regulação ética. Este estudo fornece subsídios relevantes para o desenvolvimento de estratégias de transição digital alinhadas ao ODS 8 na União Europeia.

Keywords: DEA, MCDA, AI, Human Capital

A eficiência bancária na europa – uma análise ao período 2014-2022

Leonardo Fonseca, Maria Gouveia, Carla Henriques

O setor bancário europeu atravessou um período de profundas transformações entre 2014 e 2022, impulsionado por choques como a pandemia de COVID-19, regulamentações supranacionais e a aceleração digital. Este estudo analisa a eficiência operacional de 96 bancos sistémicos sob supervisão direta do Banco Central Europeu, utilizando a metodologia Value-Based Data Envelopment Analysis e Window Analysis. Através da avaliação de inputs como custos com pessoal e ativos fixos, face a outputs como empréstimos e ativos rentáveis, investigam-se padrões de eficiência ao longo do tempo. Os resultados revelam uma melhoria sustentada da eficiência média, com destaque positivo para bancos franceses e neerlandeses. Em contrapartida, instituições de países periféricos, como Portugal, Grécia e Espanha, apresentam desempenhos inferiores. O BNP Paribas destaca-se como o banco mais eficiente, seguido pelo Santander, ambos com forte enfoque na digitalização e qualidade dos ativos. Este trabalho reforça a relevância da inovação tecnológica e da gestão estratégica de risco como pilares da eficiência no setor bancário europeu.

Keywords: DEA, MCDA, Banca

Sessão 4.1
Transportation and Delivery

Moderador: Elsa Silva

Two-index formulations for the Traveling Purchaser Problem with Incompatibility Constraints

Raquel Monteiro De Nobre Costa Bernardino, Daniel Santos

The Traveling Purchaser Problem with Incompatibility Constraints (TPP-IC) generalizes the classical Traveling Purchaser Problem (TPP) by introducing constraints that prevent certain items from being transported together. This problem arises in various real-world applications, such as hazardous materials transportation, where incompatible products must be handled separately to ensure safety and compliance. In this study, we propose a novel mixed-integer programming (MIP) formulation that models item incompatibilities using compatibility graphs. Compatibility graphs are used to model the incompatibility constraints implicitly, which makes it possible to use two-index formulations rather than a traditional three-index formulation to formulate the TPP-IC. Several compact and non-compact formulations are proposed for the TPP-IC, which are compared both theoretically and empirically. Additionally, valid inequalities are used to improve the quality of the linear programming relaxation values obtained by the formulations. A branch-and-cut framework is used to address the non-compact models. Preliminary computational results show that the two-index formulations provide better linear programming relaxation values than the three-index formulation, which we hope will contribute to the two-index models being more efficient than the three-index models in obtaining the optimal values.

Keywords: Transportation, Combinatorial, Optimization

Last-mile Delivery with Crowdshipping: a multi-objective approach

Tiago Monteiro, João Pedro Pedroso, Ana Viana

Crowdshipping has emerged as an innovative solution for last-mile delivery, in which customers can receive their groceries, parcels, or other purchases delivered by ordinary individuals (occasional couriers) instead of by a professional courier. This strategy offers faster, more cost-effective same-day delivery and greater flexibility to meet fluctuating demand. Occasional couriers (OCs) can be categorized as dedicated OCs, who register with platforms and accept delivery tasks proactively, or en-route OCs, who are in-store customers delivering goods along their usual routes. While most research has focused on minimizing delivery costs, customer satisfaction is also vital to the success of this model. This study adopts a multi-objective approach to minimize total delivery costs while maximizing service levels. The first objective includes costs associated with professional fleets, en-route OCs, and dedicated OCs. The second focuses on improving service by minimizing deviations from customers' preferred time windows. We developed a bi-objective heuristic based on the Greedy Randomized Adaptive Search Procedure (GRASP) to address these objectives, incorporating multi-directional improvement strategies. The heuristic explores the solution space using a combination of intra-route (relocate, exchange, 2-opt) and inter-route (insert, crossover, swap) operators during the local search. This method effectively approximates the Pareto front.

Keywords: Delivery, Multi-Objective, Retail, Heuristic

A new effective heuristic for the Prisoner transportation problem

Luciano Ferreira, Marcos Vinicius Milan Maciel, José Valério de Carvalho, Elsa Silva, Filipe Pereira Alvelos

The Prisoner Transportation Problem is an NP-hard combinatorial problem and a complex variant of the Dial-a-Ride Problem. Given a set of requests for pick-up and delivery and a homogeneous fleet, it consists of assigning requests to vehicles to serve all requests, respecting the problem constraints such as route duration, capacity, ride time, time windows, multi-compartment assignment of conflicting prisoners and simultaneous services in order to optimize a given objective function.
We present a new solution framework to address this problem that leads to an efficient heuristic. A comparison with computational results from previous papers shows that the heuristic is very competitive for some classes of benchmark instances from the literature and clearly superior in the remaining cases. Finally, suggestions for future studies are presented.

Keywords: Delivery, Routing, Optimization, Heuristic

A pickup and delivery problem with automated guided vehicles - modelling approaches

Paulo Ferreira, Sara Martins, Maria Santos

Pickup and Delivery Problems (PDP) and their variants are commonly found in logistics and transportation systems. This work addresses a logistic transport problem where homogeneous vehicles must fulfill transportation requests between pickup and delivery nodes, subject to service level agreements (SLAs). We compare the performance of two Mixed-Integer Linear Programming (MILP) models: one formulated as a natural PDP and the other as a sequencing problem. Results show that the sequencing-based formulation is more efficient in terms of computational performance. Furthermore, as the overall objective is to minimize both empty vehicle travel and delivery delays, we decompose the original multi-objective function into two separate single-objective models. This decomposition enables a clearer analysis of the individual impact of each objective component on the quality and structure of the solutions.
This work has been supported by national funds through FCT – Fundação para a Ciência e Tecnologia through project UIDB/04728/2020.

Keywords: Multi-Objective, Optimization, Logistics, Transportation, Delivery

Sessão 4.2
Sustainable supply chains

Moderadora: Ana Barbosa-Póvoa

Collaborative Strategies for Efficient Environmental Cost Distribution in Sustainable Supply Chains

Maria da Graça de Sousa Martinho Raposo

Growing environmental concerns and increasingly stringent regulations have compelled supply chains (SC) to rethink how they distribute the costs of environmental impacts. However, this is a complex challenge, especially when trying to balance sustainability with financial performance and fair cost-sharing among stakeholders. This paper addresses this challenge by developing a decision support tool that combines a Mixed Integer Linear Programming (MILP) model with cooperative game theory to achieve efficient cost allocations among key SC participants. The MILP model optimises network design and planning decisions to maximise the overall Net Present Value, while also monetising logistic environmental impacts, ensuring that these costs are assessed alongside conventional financial metrics. To fairly allocate these costs among suppliers, manufacturers, retailers, and logistics providers, we apply two cooperative game theory methods: the Core solution and the Shapley value. These ensure both stable and equitable cost-sharing based on collaboration and contribution. Using a real-world base case study, we show how our approach significantly reduces total environmental costs compared to non-cooperative strategies. Moreover, the Shapley value helps distribute costs more fairly, especially benefiting financially constrained stakeholders. This research offers a structured and collaborative way of building more sustainable systems through fair cost allocation.

Keywords: Supply Chain, Game, Optimization, Sustainability, Allocation

A Sustainable Approach to Urban Last-Mile Logistics: Modeling and Analysis of a Green Two-Echelon Location-Routing Problem with Eco-Conscious Customer Behavior

Valentina Bonomi, Diana Jorge, Ana Barbosa-Póvoa, Tânia Ramos

The rapid expansion of e-commerce has placed unprecedented pressure on urban logistics: Last-Mile Delivery (LMD) now poses a significant environmental impact contributing to over 30% of total CO2 emissions in the delivery sector and worsening congestion. We propose a Green Two-Echelon Location-Routing Problem (G2E-LRP), explicitly integrating (i) a heterogeneous fleet with both conventional and zero-emission vehicles of varying capacity, and (ii) eco-conscious customer decisions: clients may either receive home delivery or travel to a nearby hub, based on their individual emission rate, package size and a maximum walking/traveling green distance. The problem is formulated as a MILP and multiple cases are analyzed under varying zero-emission vehicles capacities to assess their impact on system-wide emissions and delivery distances. Exact methods were used to solve small instances, while a decomposition-based heuristic approach enabled the resolution of medium-sized cases. The model was applied to a Portuguese company offering last-mile delivery services. Results gives insights on the ability of the proposed model in balancing distances and reducing emissions.

Keywords: Routing, Optimization, Ecommerce, Sustainability

Optimising Insect-Production Facility Location: A Bi-objective Cost–Sustainability Model

Ruben Pereira, Sara Martins, Maria João Santos

The insect-production industry has been growing rapidly, creating a demand for new decision-support tools. Locating insect-production facilities, however, is difficult because site choice directly affects the cost savings and sustainability benefits that can be achieved. A poor location can undermine a project: if a plant is not close to sources of insect feed, transporting the necessary by-products becomes much more expensive and reduces the overall sustainability of the supply chain. Facility-location and supply-chain studies already address multi-objective trade-offs between cost and sustainability, but little research does so for the insect industry while taking its unique production traits into account. We set our work apart by allowing the rearing substrate to consist of a mix of by-products to represent flexibility in substrate production. In this study we formulate a bi-objective mixed-integer linear model that minimizes total cost and the environmental impact associated with each by-product. The model employs the AUGMECON ε-constraint strategy, enabling decision-makers to generate Pareto-efficient solutions and explore cost–sustainability trade-offs. To test the model, we will use the Gurobi solver in Python to compare scenarios for small, medium and large production facilities.
This work has been supported by national funds through FCT – Fundação para a Ciência e Tecnologia through project UIDB/04728/2020.

Keywords: Multi-Objective , Optimization, Location, Sustainability

Design and planning of sustainable supply chains regulated by government incentives

Marcelo Pinto, Maria João Alves, Carlos Henggeler Antunes, Samuel Moniz, Cristóvão Silva

The design of modern supply chains should account for stimulating economic growth by establishing efficient material and information flows. Yet, the same economic growth trend that fuels supply chains is also contributing to the unsustainable use of resources. This challenge provides the conceptual leverage for this work: to model the government's role as a central agent in the transition toward more sustainable supply chains. The problem is formulated as a mixed-integer bi-level optimization problem. The government is the leader that allocates financial incentives aiming to minimize the environmental impact of technologies and transport modes, favoring low-emission options. The supply chain is the follower that decides on facility openings, technology assignments, production and transportation quantities, and selects transport modes to minimize total costs responding to those incentives. To solve this problem, we propose a deterministic bounding procedure, which is adapted to the hierarchical characteristics of our problem where upper-level constraints include lower-level variables. The convergence is obtained by iteratively computing upper and lower bounds to the leader's objective function.

Keywords: Supply Chain, Sustainability, Bi-Level, Optimization

Sessão 4.3
Moderador: Rui Borges Lopes

Teams management and scheduling

Revisão de literatura sobre escalonamento cíclico de turnos com rotação de folgas e horários fixos

Dorirley Alves, Rui Borges Lopes

No problema de escalonamento cíclico de turnos com rotação de folgas e horários fixos o objetivo é alocar trabalhadores em ciclos que combinem turnos fixos (manhã, tarde, noite) e folgas rotativas, garantindo operações ininterruptas em setores como saúde e indústria. O problema envolve elevada complexidade computacional (sendo classificado como NP-difícil) devido a múltiplas restrições: legais (limite de dias consecutivos, descanso semanal), operacionais (cobertura total de turnos, equidade de carga horária, minimização de custos) e humanas (respeito aos ritmos biológicos, evitando impactos à saúde como fadiga). Nesta apresentação será abordada uma revisão de literatura sobre o tema, com foco na classificação dos diferentes tipos de problemas, modelos existentes na literatura, bem como nas principais características que eles abordam. Serão também discutidas lacunas na literatura e oportunidades para pesquisas futuras.

Keywords: Scheduling, Workers, Optimization, Literature Review

Optimization of home care visits: A study case on family support organizations

Maria Isabel Gomes, Margarida Lopes

Family dynamics play a crucial role in the development of children and youth. When these dynamics are negative, they can put children at risk, potentially resulting in the loss of parental rights and subsequent institutionalization, an outcome that has been recognized as undesirable. Consequently, there has been a growing emphasis on early intervention, aiming to work with families to develop the skills needed to improve their relationships and prevent institutionalization. Some organizations are responsible for providing this type of support. However, the growing number of families in need, combined with a fixed number of professionals, heavy bureaucratic workloads, limited availability of both families and workers, and manual scheduling due to a lack of resources, creates significant challenges. These factors complicate the assignment of workers to families, and scheduling and execution of visits, making it difficult to meet families' needs and comply with court-ordered deadlines. To address these challenges, this work proposes a Mixed Integer Linear Programming (MILP) model to improve visit planning. By providing tactical plans that determine which professionals visit which families and when, the model aims to maximize completed visits, balance workloads, and promote a healthier work-life balance for staff. Ultimately, this approach enhances service delivery and better support of vulnerable families.

Keywords: Scheduling, Optimization, Assignment, Workers

Scheduling crew reserve duties with flexible time windows

Maria Tovar, Sara Cruz, Ana Wemans, Jorge Roussado, Ricardo L. Saldanha, Ana Paias

The crew reserve duty scheduling problem involves generating reserve duties months in advance. These duties are daily periods where crew members are on call at their operational bases, ready to perform jobs assigned to them by dispatchers, that are handling disruptions typically during the day of operation. This optimisation problem is challenging because the exact time and place where a reserve duty is needed is unpredictable and can vary throughout the year. We address a new variant of this problem where reserve duties have a flexible time window that will be fixed closer to the day of operation. The fixed duties can be different for different days according to what is more likely to be the reserve needs on those days. In order to solve this problem we propose several alternative approaches combining in different ways greedy heuristics, integer linear programming, stochastic simulation and possibly other methods. We compare their performance based on evaluation tests performed with data from a major Northern European passenger railway operator. We also compare scenarios with flexible time windows against those with rigid ones.

Keywords: Scheduling, Workers, Transport-Rail, Optimization, Simulation

Workforce Strategic Productivity Analysis and Optimization in a Retail Company

Afonso Caldeira Neto dos Santos Neves

Labor costs account for a significant portion of operational expenses in the food retail sector, making workforce optimization a strategic priority. This work develops a data-driven methodology to determine the optimal number of Full-Time Equivalents (FTEs) needed per store, function, and week, balancing operational efficiency with service level. The proposed framework consists of two complementary components. The first is an efficiency model based on Mixed-Integer Linear Programming (MILP), which estimates the minimum FTEs required based on a store's operational characteristics. The second component is a service level model that utilizes second-degree regression to predict the additional FTEs required to maintain historical service standards. Both models are applied independently by function and within store clusters sharing similar operational profiles. The methodology was implemented in a real-world setting across more than 350 stores of a major Portuguese food retailer, using large-scale datasets processed with PySpark and optimized with Gurobi. Results demonstrate the ability to decompose observed labor usage into efficiency, service, and inefficiency, offering actionable insights for strategic workforce planning. In addition to retrospective evaluation, the framework supports forward-looking simulations under varying service level targets and store scenarios. This work contributes a scalable, interpretable, and robust approach to labor productivity management in complex retail environments.

Keywords: Optimization, Workers, Productivity, Retail, Simulation

Sessão 4.4
Moderadora: Carina Pimentel

Operations management and logistics

Human-Centered Optimization in Logistics: A Case-Based MILP Model for Safer Picking

Monica Gaboleiro, Maria Isabel Gomes, Isabel L. Nunes

Increasing performance while minimizing operational risk is essential for successful logistics operations. However, these objectives often conflict—particularly in distribution centers, where picking operators are exposed to fatigue and injury risks that compromise both safety and individual efficiency. This study presents a first modelling approach to address this trade-off, based on a real-world case study from a food retail company. The proposed mixed-integer linear programming (MILP) model optimizes the assignment of picking tasks to simultaneously enhance operator performance and reduce injury risk. In doing so, it contributes to the broader goal of sustainable entrepreneurship by aligning operational effectiveness with worker health and well-being—two critical pillars of long-term organizational resilience. The case study demonstrates how analytical models can be tailored to address complex, human-centered operational challenges. By integrating performance and safety into a unified decision-support tool, this research underscores the potential of operations research to promote more balanced and sustainable logistics systems.

Keywords: Logistics, Assignment, Workers, Safety, Health

Otimização Não Linear para a Geração de Robôs Antropomórficos em Tarefas de Reposição

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Os modelos de otimização desempenham um papel essencial em ambientes industriais, especialmente na Indústria 5.0, onde os sistemas robóticos avançados são fundamentais para aumentar a eficiência e a adaptabilidade. Este trabalho aborda problemas de otimização de grande escala e altamente não lineares, que surgem na geração de movimentos semelhantes aos humanos para um robô antropomórfico a realizar tarefas de reposição de prateleiras. A geração destes movimentos implica a formulação e resolução de problemas de otimização complexos relacionados com as posturas angulares dos braços e a evitar a colisão com obstáculos no espaço de trabalho do robô. O impacto de diferentes níveis de simplificação na eficiência computacional é avaliado através de técnicas numéricas de otimização adaptadas a problemas de grande escala. Os resultados demonstram que níveis moderados de simplificação reduzem significativamente o tempo de computação, enquanto níveis mais elevados podem comprometer o desempenho. As análises estatísticas efetuadas confirmam a importância de equilibrar a redução do número de restrições e variáveis de decisão com a eficiência do solver ao lidar com problemas tão exigentes do ponto de vista computacional. As conclusões evidenciam os desafios e as oportunidades na otimização de movimentos robóticos para aplicações industriais, contribuindo para o desenvolvimento de sistemas robóticos mais eficientes e com comportamentos mais semelhantes aos humanos no retalho inteligente e para além dele.

Keywords: Optimization, Industry, Robots

A Hybrid Framework for the Integrated Production and Routing Problem with Sequence-Dependent Setups and Multi-Period Constraints

Mário Leite, Telmo Pinto, Cláudio Alves

This work addresses the Integrated Production Routing Problem (IPRP), a challenging combinatorial optimization problem inspired by the real-world operations of a Brazilian furniture manufacturer. The IPRP involves coordinating production and distribution decisions over a finite planning horizon, divided into periods, for multiple products characterized by heterogeneous attributes, such as weight, size, and number of components. This IPRP incorporates several constraints, including sequence-dependent setups, safety stocks and limited production capacity during periods, heterogeneous vehicle fleets, multi-period routing, and customers with multiple time windows and deadlines. The objective is to minimize the total cost, which comprises setup costs, inventory holding, and transportation expenses. This integration of production and distribution decisions introduces temporal and spatial interdependencies rendering the problem NP-hard and computationally intractable for realistic instances when using exact methods. To tackle this problem, we propose a hybrid approach that combines a Variable Neighborhood Search metaheuristic with an embedded Integer Programming model. The proposed approach is evaluated through extensive computational experiments on benchmark instances, demonstrating its effectiveness in solving the IPRP and handling its inherent combinatorial complexity.

Keywords: Production, Routing, Combinatorial, Heuristic

Modelo de otimização robusta para a gestão da cadeia de abastecimento agroflorestal residual

Saeed Tasouji Hassanpour, Reinaldo Gomes, Carina Pimentel, Radu Godina

Este estudo propõe um modelo de otimização multi-período para um problema de Gestão da Cadeia de Abastecimento de Biomassa Residual. O modelo aborda os desafios associados à acumulação de biomassa, à logística de transporte e à capacidade de armazenamento, assegurando simultaneamente a viabilidade económica. É utilizada uma abordagem de otimização robusta baseada em cenários para ter em conta as incertezas na disponibilidade da biomassa, e as flutuações da procura, refletindo diferentes condições de funcionamento. São apresentados resultados para uma instância baseada num estudo de caso real no Centro de Portugal, demonstrando a sua aplicabilidade prática na otimização da logística da biomassa. Este estudo contribui para a literatura ao colmatar a lacuna entre os modelos teóricos de otimização e a gestão prática da cadeia de abastecimento, oferecendo uma ferramenta robusta de apoio à decisão para os decisores políticos e as partes interessadas da indústria.

Keywords: Supply Chain, Uncertainty, Forest

Sessão 5.1
Vehicle routing

Moderador: Pedro Martins

Route planning in a condominium company using mathematical optimization

Lara Rocha, Pedro Martins

This work focuses on planning daily routes for a group of employees from a condominium company.
Given a set of employees and a set of customers with pre-scheduled visits, we want to build double-open routes to guarantee visits to all customers, ensuring that each customer is visited by an employee with the appropriate skills to carry out the required activity. The travel times between customers and the service time at each customer are known. The problem includes time windows for visiting customers, each employee has a maximum working time and the daily working period is between 9 AM and 6:30 PM. The routes respect the lunch period if they extend from morning to afternoon. The aim is to minimize the distance covered by all routes.
The distances and times between customers are collected via an API to Microsoft Azure; and the solutions are then displayed on Bing Maps.
The results obtained show the operational advantages of an efficient and effective vehicle route planning in a specific condominium management company. The model can be extended to other service provider companies.

Keywords: Routing, Delivery, Optimization

One Model, Many Constraints: Multi-task learning for Multi-depot Vehicle Routing Problems

Arthur Corrêa, Samuel Moniz, Cristóvão Silva

The Vehicle Routing Problem (VRP) is a fundamental combinatorial optimization challenge with wide-ranging applications in logistics and transportation. While machine learning has recently gained traction as a scalable alternative to traditional solvers, most existing methods are designed for a single specific VRP variant, limiting their generalizability to solve a diverse range of VRP problems. To address this, Multi-task learning (MTL) — a learning paradigm in which a single model is trained to solve multiple related tasks — has emerged as a promising method, enabling shared learning across different VRP formulations. However, prior MTL efforts have focused mainly on single-depot VRPs, overlooking the more realistic and complex Multi-Depot VRP (MDVRP). In this work, we introduce a reinforcement learning-based MTL model capable of solving not only the classic MDVRP, but also other variants incorporating backhauls, open routes, route duration limits, time windows, and any combination of these constraints. In total, our unified model can solve 16 distinct MDVRP formulations without requiring architectural changes or retraining. Extensive experiments show that our approach achieves minimal solution gaps compared to state-of-the-art meta-heuristics, while operating at a fraction of their computational time.

Keywords: Routing, Combinatorial Optimization, Machine Learning

A Rich and Heterogeneous Fleet Vehicle Routing Problem for Fuel Lane Management and Wildfire Prevention

Philippe Almeida Mirault, Pedro Amorim, Ricardo Soares

Wildfires pose a significant threat to ecosystems, frequently having detrimental effects on the environment and the economy. One of the main reasons for their ignition and propagation is the abundance of unmanaged vegetation, particularly close to linear infrastructures. Countries prone to these hazards have established fuel lane management strategies to mitigate fire risks. Fuel lane management has received special attention in Portugal, as it has particularly low productivity and performance in forest management operations. This project addresses these problems by developing a model for fuel lane management operations, integrating heuristics, namely *Adaptive Large Neighborhood Search* (ALNS). The plan schedules the allocation of specific machines to different plots over multiple periods, considering operational and environmental costs. The available machines are heterogeneous thus, for different area types, they provide different productivity, which leads to varying service times. Additionally, this problem can be characterized as a Vehicle Routing Problem (VRP) with a limited heterogeneous fleet, making it essential to determine optimal assignments that balance effectiveness and efficiency. Unlike traditional VRP models, whose main objective is to minimize travel costs, this problem incorporates additional constraints related to the fire risk of each plot. Fire risk is crucial in determining the priority of clearing operations, even if this results in a less efficient route. This research focuses on a case-study in Portugal, exploring the best routes for forest plot clearing operations that satisfy both operational demands and the environmental context of the region.

Keywords: Fire, Forest, Heuristics, Optimization, Routing

A hybrid optimisation method for vehicle routing in a fleet of multi-compartment vehicles with controlled temperature settings

Ana Maria Rodrigues, Elif Göksu Öztürk, Isabel Cristina Lopes

This work addresses the Multi-Compartment Vehicle Routing Problem (MCVRP), relevant for transporting goods that must remain separated or require distinct temperature conditions. We consider a predefined fleet consisting of three vehicle types: room temperature, refrigerated, and dual-compartment (room temperature and refrigerated). The distribution scenario involves multiple pick-up points and a single logistics center. The primary objective is to minimize total operational costs, which include fixed vehicle expenses, maintenance, and time-related costs associated with transportation and loading activities. Another factor to consider is the increased energy consumption of refrigerated compartments, which require more fuel or electricity to cool, impacting the cost structure even more. To address this, we propose a three-step hybrid solution approach. First, demand points are grouped in an optimal number of clusters. Then, we perform route optimization within each cluster, taking into account vehicle capacity and demand compatibility. In the final step, each cluster is treated as a single node, and inter-cluster routing is optimized. Linear programming is applied in the latter two steps. This method combines the strengths of exact and heuristic techniques, delivering high-quality solutions while ensuring cost-effective fleet utilization.

Keywords: Routing, Optimization, Heuristics

Sessão 5.2
OR in Energy 2

Moderadora: Eliana Costa

Decision support system for sustainable implementation of hydrogen supply chains in Brazil

Leonardo Santana, Fernando Pessoa, Ana Barbosa-Póvoa

Hydrogen is a key element in the global transition toward a low-carbon economy, with green hydrogen offering significant potential to decarbonize industries and energy systems. This study aims to develop a decision support system for the optimized implementation of a Hydrogen Supply Chain (HSC) in Brazil. Key aspects identified in the literature will be addressed, including the need for efficient optimization models, the integration of the social pillar of sustainability, and the notable lack of research focused on Brazil as a study area. The proposed decision support system is structured in two stages. The first formulates the HSC as a Mixed-Integer Linear Programming (MILP) problem, considering decisions related to facility location, production capacity, transportation, and hydrogen storage, while integrating uncertainties in input availability and demand. The second stage employs a Mixed-Integer Nonlinear Programming (MINLP) model to more accurately represent the nonlinearities of hydrogen production processes, thereby improving decision-making precision. Preliminary results indicate that economies of scale play a critical role, reducing both financial costs and greenhouse gas (GHG) emissions compared to alternative scenarios. The study underscores the importance of aligning production strategies with regional renewable energy resources to enhance cost-effectiveness and sustainability.

Keywords: Supply Chain, Hydrogen, Energy, Optimization, Sustainability

Integrated Battery Management in Photovoltaic Power Plants: A Real Case Study

Ana Borges, Margarida Correia, Eliana Costa

The transition to renewable energy presents significant challenges in managing production and consumption efficiently. This study addresses the optimization of the energy usage for owners of photovoltaic plants equipped with storage systems. The main objective is to develop a decision-support model that maximizes profitability by intelligently and dynamically managing consumption and storage of electricity, by considering OMIE market prices and consumption costs. The research is supported by real operational data from a photovoltaic installation with battery storage. Historical data on electricity consumption, solar energy production, and market prices were analyzed to identify inefficiencies in conventional reactive management strategies. A predictive approach was proposed, integrating forecasts of market prices, weather conditions, and consumption patterns. A Mixed-Integer Linear Programming (MILP) model is currently being developed to optimize the charge and discharge cycles of the batteries. This model considers technical constraints and market dynamics to generate cost-effective energy management strategies. Preliminary results indicate that strategic battery usage significantly reduces operational costs, improves energy autonomy, and increases profitability. The approach is scalable and adaptable, offering a replicable framework for other small-scale renewable energy producers aiming to enhance sustainability and efficiency.
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Keywords: Renewable Energy, Solar, Optimization

A comprehensive optimization framework for designing hybrid offshore renewable energy systems

Masoud Golalikhani, Flávia Barbosa, Luís Guimarães, Luciana Yamada

Hybrid offshore renewable energy systems (HRES) offer a promising solution to mitigate the variability of renewable energy sources. Specifically, combining offshore wind turbines, solar photovoltaics, and wave energy converters enhances power stability by leveraging their complementary characteristics. However, designing an efficient HRES requires a comprehensive approach that addresses key challenges across the entire project lifecycle. Nevertheless, existing studies often address these challenges separately and rely on oversimplified assumptions that fail to reflect real-world conditions, resulting in design decisions that may compromise economic viability. To address this, we propose an integrated optimization framework that simultaneously optimizes layout, sizing, and cable-routing decisions, while accounting for realistic operation and maintenance factors. In particular, the model determines the optimal number and placement of devices and selects the most appropriate type and configuration of both inter-array and export cables to maximize the project's net present value. A Markov-based model is incorporated to represent critical system states throughout the lifecycle, including operational, degraded, and failed conditions, as well as preventive and corrective maintenance. This enables more accurate estimations of availability, accessibility, energy output, and overall economic performance. Case studies based on real-world examples provide practical insights to support informed investment and planning decisions for HRES.

Keywords: Renewable Energy, Optimization, Uncertainty-Markov

Avaliação da Pobreza Energética na União Europeia: Uma Abordagem Multidimensional e Dinâmica (2015–2023)

Daniel Matos, Maria Gouveia, Carla Henriques

A pobreza energética permanece uma preocupação relevante na União Europeia, agravada pela falta de uma definição harmonizada e de metodologias comparáveis entre países. Este estudo propõe a construção de um indicador composto e multidimensional, com base no modelo Value-Based Data Envelopment Analysis e na sua extensão dinâmica Window Analysis, complementado pela abordagem de Club Convergence. A análise considera cinco dimensões essenciais: dificuldade em manter a casa aquecida, dívidas em serviços básicos, condições habitacionais degradadas, consumo energético ajustado ao clima e risco de pobreza ou exclusão social. Com dados do Eurostat e do EPAH, tratados em Python, foram avaliados os 27 Estados-Membros entre 2015 e 2023. Os resultados revelam fortes assimetrias regionais: países do Norte e Centro da Europa, como Suécia e Alemanha, apresentaram os melhores níveis de eficiência, enquanto países do Leste e Sul, como Roménia e Grécia, enfrentam desafios estruturais contínuos. Portugal e Lituânia destacam-se pela melhoria sustentada, fruto de políticas de reabilitação urbana e tarifas sociais. A Polónia registou avanços recentes significativos. A análise de convergência identificou três grupos distintos, evidenciando divergência crescente entre países. A inovação deste estudo reside na articulação metodológica entre o Value-Based Data Envelopment Analysis dinâmico e a club convergence, permitindo captar a evolução contextual da pobreza energética. Conclui-se que são necessárias políticas diferenciadas para garantir um progresso mais equitativo em direção ao ODS 7 — com foco em programas de eficiência no Sul e investimentos estruturais no Leste da Europa.

Keywords: DEA, MCDA, Energy, Inequality

Sessão 5.3
Hard optimization problems

Moderador: Samuel Moniz

New ideas on Monte Carlo tree search for optimization

João Pedro Pedroso

Monte Carlo tree search (MCTS) has shown significant success in game playing, achieving state-of-the-art results in many complex domains. While there are known applications in optimization, they often don't fully capitalize on the problem-specific knowledge available. This work addresses this gap by proposing adaptations of MCTS tailored for optimization problems. We focus on enhancing the exploitation of problem-specific heuristics, exploring methods to integrate these heuristics directly into the selection and expansion phases of the MCTS algorithm.
We also introduce strategies for a more elaborate exploitation of the incumbent solution. This involves incorporating ideas from local search techniques into the MCTS framework. By strategically exploring the vicinity of promising solutions, we aim to improve the quality of the final result.
Finally, we propose the adoption of non-deterministic selection rules within the MCTS algorithm. These rules are designed to promote a more diversified exploration of the search tree, particularly at the topmost levels. By introducing stochasticity into the selection process, we aim to mitigate stagnation caused by excessive breadth at those levels.
These ideas will be illustrated with the graph coloring problem, and some applications on timetabling will be analyzed.

Keywords: Monte Carlo Tree Search, Optimization, Heuristics, Stochastic, Timetabling

A mathematical formulation for the imaging and communication scheduling problem for super-agile Earth observation satellites

Margarida Caleiras, Samuel Moniz, Paulo Nascimento

Earth Observation Satellites (EOSs) are designed to collect images of Earth's surface for a wide range of applications, such as disaster response, environmental monitoring and resource management. With the increasing number of orbiting EOSs, efficient scheduling of satellite operations has become a critical challenge. To ensure effective use of these complex systems, it is essential to develop advanced scheduling methods that manage both image acquisition and data transmission. However, due to the rapid development of new generations of satellites, Super-Agile EOSs (SAEOSs), capable of dynamic maneuverability and real-time attitude control, existing scheduling approaches must be revisited. Thus, the literature on SAEOS scheduling is growing to meet these new demands. Still, current studies focus only on image acquisition, neglecting that all collected data must be transmitted to the ground. Furthermore, when realistic constraints such as multiple SAEOSs, diverse imaging targets, and energy and memory limitations are considered, the problem becomes even more complex. In this sense, this paper investigates and formally defines the imaging and communication scheduling problem for SAEOSs in multi-type target scenarios, while considering energy and memory constraints. This work lays a foundational step toward the development of efficient optimization strategies for this emerging class of NP-hard scheduling problems.

Keywords: Scheduling, Space, Optimization, NP-Hard

A Novel Derivative-Free Method with Improved Complexity for Nonsmooth Convex and Strongly Convex Optimization

Rohollah Garmanjani

Derivative-free methods—also known as black-box or zero-order methods—are crucial when derivative information is unavailable or unreliable. We introduce a novel algorithm that, for nonsmooth convex objectives, achieves a worst-case complexity bound proportional to the inverse square of a specified accuracy tolerance—substantially improving over a previously developed method in the literature. For nonsmooth strongly convex objectives, our method further improves to a complexity bound that grows only logarithmically with the inverse of the accuracy tolerance. Importantly, in the general nonsmooth nonconvex setting, our algorithm matches the complexity bound of a closely related existing method.

Keywords: Optimization, Derivative-Free, Nonsmooth

Sobre clutters minimalmente não ideais

Paulo Monteiro, João Soares

Um *clutter* é um par $\mathcal{C} \equiv (V, E)$, onde E (os elementos de $\mathcal{C}$) denota uma família de subconjuntos, de um conjunto não vazio e finito V (os vértices de $\mathcal{C}$), tal que nenhum dos elementos está contido noutro. A teoria de clutters, outrora referida como *blocking* e *antiblocking* (Fulkerson'70), permite abordar, de modo elegante, questões diversas relacionadas com problemas de *set packing* e *set covering*, nomeadamente a caraterização de integralidade dos poliedros subjacentes a esses problemas e o estabelecimento de relações to tipo min-max em problemas de otimização combinatória (o valor mínimo de um problema é igual ao valor máximo de um outro).
Um clutter $\mathcal{C}$ é ideal se o poliedro (das coberturas de $\mathcal{C}$) $Q(A) \equiv \{\mathbf{x}\colon A\mathbf{x} \geq \mathbf{1}, \mathbf{x} \geq \mathbf{0}\}$ é inteiro, onde $A \equiv M(\mathcal{C})$ denota uma matriz de zeros e uns cujas linhas são os vetores característicos dos elementos de $\mathcal{C}$. Um menor de $\mathcal{C}$ é um outro clutter que resulta de $\mathcal{C}$ após uma ou mais operações de *remoção* ou *contração* de um vértice de $\mathcal{C}$. Um clutter é minimalmente não ideal, ou simplesmente mni, se não for ideal mas todos os seus menores forem. Lehman'79 provou que todos os clutters mni têm uma estrutura precisa, são a extensão de clutters definidos por uma matriz de Lehman. Uma matriz de Lehman é uma matriz Y r-regular de zeros e uns tal que $YZ^T = dI + \mathbf{1}\mathbf{1}^T$, para algum inteiro positivo d e alguma matriz Z de zeros e uns. Nesta palestra mostraremos que as matrizes associadas a planos projetivos, embora sendo definidas por matrizes de Lehman, não podem desempenhar esse papel.

Keywords: Set Covering, Combinatorial Optimization

Sessão 5.4
Optimization with uncertainty

Moderador: Filipe Alvelos

Fleet Composition under Uncertainty: A Multi-Objective Optimization Approach

Parisa Ahani, Maria Isabel Gomes

This study tackles the fleet composition problem for a transport operator facing uncertainties in energy prices, vehicle costs, and operational expenses over a defined planning horizon. With a limited budget, the decision-maker must choose among vehicle types—such as diesel with lower upfront costs but higher running expenses, and electric with the opposite profile. To manage long-term cost and risk, the research proposes a multi-objective mixed-integer quadratic programming (MO-MIQP) model. This model minimizes total cost of ownership (including purchase, energy, maintenance, depreciation, and emissions) while also reducing financial risk linked to uncertain parameters. A Pareto front guides trade-off decisions between cost and risk. The model incorporates ARIMA-based forecasts for energy and vehicle prices, integrating them into both cost and risk functions. This approach offers practical insights into balancing economic and environmental considerations in fleet planning, supporting resilient, data-driven decision-making.

Keywords: Multi-Objective, Optimization, Forecasting, Fleet, Uncertainty

Evolutionary Adaptive Policies for the Stochastic Dynamic Inventory-Routing Problem

Francisco Maia, Gonçalo Figueira, Fábio Neves-Moreira

The stochastic dynamic inventory-routing problem (SDIRP) integrates inventory management and vehicle routing under uncertainty, where customer demands are revealed progressively over time. This research aims to provide new insights into resolving an SDIRP, focusing on a central warehouse that periodically distributes homogeneous goods to a set of geographically dispersed customers. Decision-making involves a three-step policy: calculating a delivery priority for each customer, determining delivery quantities based on an (s, S) inventory rule, and computing a vehicle route via an exact method. A simulator was developed to replicate the problem's dynamics and enable policy training and evaluation across multiple scenarios. The priority rule is obtained as a combination of key features extracted from the problem instances, relying on two evolutionary methods: Genetic Programming and Genetic Algorithms. Our policies were evaluated on problem instances with up to 50 customers and 20 periods, considering multiple demand uncertainties, holding and shortage costs, and vehicle capacities. The obtained results highlight a competitive performance in total cost reduction compared to several myopic and direct lookahead benchmarks, enhancing stock balance and minimizing travel distances.

Keywords: Stochastic, Routing, Inventory, Genetic Algorithm, Optimization

Managing Supply Chain Disruptions through Design Science Research: A Mathematical Modeling and Simulation Approach

Fábio Lopes, Ana Amaro

This study examines supply chain dynamics through the development of a mathematical optimization model—considered as a research artifact—designed to analyze supply chain behavior under various disruption scenarios. These may affect supply, demand, or pricing conditions. A mathematical formulation of the problem was developed and implemented using the python programming language. To validate the proposed model, a case study concerning the production of coffee capsules was conducted, simulating multiple operational scenarios across the supply chain. These scenarios encompass the key stages of the chain—namely supplier, manufacturer, distributor, and retailer—as well as distinct planning and operational requirements. The Design Science Research (DSR) methodology guided the research process, enabling a systematic evaluation of the impacts of disruptive factors (e.g., supply failures, delivery delays, price fluctuations), their magnitude (total, partial, or other disruptions), and the duration of these occurrences. This work contributes to a deeper understanding of supply chain dynamics, particularly in terms of decision-making and operational planning under uncertainty and disruption.

Keywords: Supply Chain, Disruption, Uncertainty, Planning, Optimization

Bi-objective Pollution Routing Problem with Uncertain Demand and Travel Time

João Martins, Carlos Henggeler Antunes, Telmo Pinto

The Vehicle Routing Problem and its many variants have been extensively studied over the years due to the various gains enabled by efficient route planning. However, many routing models consider cost minimization by focusing solely on factors such as distance traveled or the number of vehicles utilized, often neglecting other considerations that affect costs and disregarding the environmental impact of solutions. This fact has motivated the proposal of novel formulations aimed at better capturing the complexities of real-world logistical operations. Moreover, the inherent uncertainty in several factors has led to increasing interest in models capable of handling uncertain data, thereby providing solutions that are more useful in practice. In this presentation, we study the Pollution Routing Problem, a variant of the VRP Problem designed to account for driver wages and fuel consumption costs, and we introduce a bi-objective model that considers environmental impact and operational expenses while accounting for uncertainties in travel times and customer demand. We perform extensive computational experiments on benchmark instances to assess the impact of hedging against uncertainty on solution quality and the Pareto front.

Keywords: Multi-Objective, Sustainability, Routing, Uncertainty

EstudIO

Um modelo de agendamento de exames universitários

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Descrição do problema

O processo de marcação de exames em contexto universitário envolve decisões complexas, com múltiplas variáveis e restrições associadas a cursos, anos, professores, estudantes, salas e exames. Normalmente, a marcação de exames é feita manualmente, procurando encontrar a melhor solução, tanto para os professores como para os estudantes.

No entanto, surgem situações em que, manualmente, é muito difícil encontrar uma solução admissível, quanto mais uma solução próxima da solução ótima, conciliando todos os diferentes cursos e anos, uma vez que devem ser planeados em conjunto, por partilharem recursos, como salas ou professores, e mesmo unidades curriculares[1].

Relevância do problema

A relevância deste problema ultrapassa o domínio administrativo, uma vez que afeta diretamente a experiência dos estudantes e a logística das instituições.

A gestão eficiente dos horários de exames é essencial para o funcionamento harmonioso das instituições de ensino superior. Uma distribuição mal planeada pode sobrecarregar estudantes com exames em dias consecutivos, ou até no mesmo dia, o que dificulta a logística de salas e aumenta o esforço necessário para a vigilância das provas.

Metodologia

A resolução do problema foi inicialmente abordada com um modelo de Programação Linear resolvido com python utilizando a biblioteca *PuLP*, com o objetivo de maximizar a distância entre exames do mesmo curso e ano. No entanto, para instâncias reais, a resolução exata tornou-se impraticável devido ao tempo computacional elevado.

Face a esta limitação, foi desenvolvida uma meta-heurística baseada no *Biased Random-Key Genetic Algorithm (BRKGA)*[2, 3]. Nesta heurística, são geradas soluções. Cada solução é representada por um vetor de chaves aleatórias, interpretadas por um *decoder* que constrói um calendário completo de exames. A função *fitness* avalia a solução com base na proximidade entre exames incompatíveis, no cumprimento de restrições hard e soft e na utilização eficiente de salas.

A interpretação dos genes ocorre em etapas no decoder, começando pela definição de um horário base (slot) para cada curso-ano, promovendo consistência interna. Em seguida, outro conjunto de genes define o dia do exame, evitando feriados e fins de semana. Apesar de existir um horário predefinido por curso-ano, cada exame tem uma probabilidade 85 % de o manter, permitindo alguma flexibilidade para resolver conflitos. Por fim, um gene por curso determina o ponto de partida para a alocação de salas, favorecendo a concentração espacial dos exames e otimizando a logística.

O problema foi abordado e resolvido considerando unidades curriculares, cursos, anos, professores, salas, tipos de sala, dias e slots horários, e tendo como **variáveis de decisão** a alocação de exames a salas e a horários.

As **restrições** do modelo dividem-se em *hard*, que devem ser sempre respeitadas, e *soft*, preferenciais e mais flexíveis.

As restrições ***hard*** são:

- Não ter dois exames considerados incompatíveis, como, por exemplo, dois exames de unidades curriculares obrigatórias do mesmo ano curricular e do mesmo curso, marcados para o mesmo dia
- Nenhum exame pode ser marcado para sábados, domingos ou feriados
- Um exame de um determinado ano curricular N não pode ser alocado para o mesmo dia e horário que exames dos anos curriculares N-1 ou N+1 do mesmo curso
- Cada exame tem de ser marcado numa sala adequada ao seu tipo, por exemplo, uma sala com computadores, se necessário
- Um professor não pode ter dois exames de unidades curriculares sob sua responsabilidade marcados para o mesmo dia e hora
- Em cada sala, dia e hora só pode ser alocado um exame de uma unidade curricular
- Salas atribuídas a um dado exame têm de ter lugares suficientes para todos os alunos inscritos nessa unidade curricular
- Todos os exames previstos têm de ser marcados
- Exame de época normal e de época de recurso devem ter, pelo menos, um intervalo de 10 dias
- Se dois exames tiverem de ser coincidentes, estes devem ser agendados para o mesmo dia e hora

As restrições ***soft*** são:

- As unidades curriculares consideradas difíceis não podem ter mais nenhum exame marcado no mesmo dia, dentro do mesmo curso
- Em casos em que exista mais do que um exame, dentro do mesmo curso e ano curricular, considerado difícil, estes devem ser intervalados com, pelo menos, uma semana
- As salas alocadas a cada exame devem ser o mais próximas possível
- Exames de um dado ano curricular, de um dado curso, devem ser alocados para a mesma hora, independentemente do dia

A **função objetivo** analisa e maximiza a distância entre os diferentes exames de cada ano, dentro de cada curso, e atribui pesos variáveis dependendo do intervalo de dias verificados em cada solução.

Adicionalmente, foi desenvolvida uma função de exportação automática para Excel, facilitando a análise e validação do calendário por parte dos serviços académicos e coordenadores de curso.

Por fim, foi criada uma versão do modelo que, em vez de marcar salas para cada exame de forma individual, marca salas que vão ser partilhadas entre exames diferentes para reduzir o número de salas necessárias.

Resultados

O modelo foi testado com dados reais da Faculdade de Engenharia da Universidade do Porto, envolvendo centenas de exames, dezenas de salas, centenas de professores e diferentes tipos de sala. A abordagem revelou-se capaz de gerar soluções viáveis e equilibradas, demorando cerca de 30 horas no primeiro teste desenvolvido.

Os resultados obtidos são promissores e validam o modelo em contexto real, com feedback positivo preliminar. O sistema encontra-se em fase final de validação institucional, continuando a fase de testes, com potencial para ser adotado em próximas épocas de exames e expandido para outras faculdades ou instituições com problemas semelhantes.

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Optimization of berth allocation and tugboat scheduling under uncertainty

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Problem description

This research directly addresses the integrated coordination of berth allocation and tugboat scheduling within container port operations. Although traditionally modeled as separate problems, the Berth Allocation Problem (BAP) and the Tugboat Scheduling Problem (TSP) are inherently interconnected, as berthing positions and timings directly influence tugboat requirements and vice versa. This work introduces a comprehensive optimization framework that models these decisions simultaneously. The BAP component is formulated in its continuous form, allowing vessels to be assigned to any location along the quay, which significantly enhances flexibility and resource utilization. Concurrently, the TSP considers crucial constraints such as assignment, service duration, and the sequential nature of tug operations. By integrating these components, the model successfully captures both spatial and temporal inter-dependencies, offering a holistic view of berth-tug coordination. Specifically, it develops a two-stage stochastic Mixed-Integer Linear Programming (MILP) model to jointly optimize vessel positioning along the quay and tugboat allocation, incorporating uncertainty in vessel arrivals and service durations through a finite set of discrete scenarios derived from empirical distributions.

Problem relevance

Modern container terminals, such as those in Shanghai, Rotterdam, and Singapore, face mounting pressure to reduce vessel turnaround times while handling increasing traffic volumes and constrained physical resources. Despite the critical interdependence between berth allocation and tugboat operations, these planning tasks are typically executed in isolation, often by separate stakeholders or systems. This disjointed approach results in operational inefficiencies, including idle tugboats, delayed berthing, and poor utilization of port assets.

Berth allocation and tug scheduling are intrinsically linked: a vessel cannot berth without available tug assistance, and tugboat operations depend on berth readiness. When these decisions are decoupled, the result is frequent misalignment. For example, a ship may be assigned a berth but remain at anchorage due to tug unavailability. Legacy practices such as First-Come-First-Served (FCFS) exacerbate this fragmentation by ignoring opportunities for system-wide optimization. Integrating berth and tugboat planning enables synchronized scheduling, reducing total port operating costs, minimizing idle time, and cutting fuel consumption through better alignment of vessel arrivals and tug deployment. Empirical studies confirm that joint optimization leads to faster turnaround, more efficient resource allocation, and improved service levels, especially in high-throughput environments.

Port operations are subject to high uncertainty, ranging from unpredictable arrival times to equipment failures and weather disruptions. However, most existing models assume deterministic inputs. By incorporating uncertainty directly into the optimization process, this research improves schedule resilience and operational adaptability.

Methodology

The integrated decision-making framework developed in this research is built upon two established modeling foundations. The berth allocation component draws from the continuous berth allocation

model by Lee et al. (2010), which effectively represents vessel mooring in a continuous time-space diagram, enabling precise spatial positioning and service time modeling. The tugboat scheduling component is informed by the deterministic structure of the model proposed by Kang et al. (2020), which focuses on assigning a finite fleet of heterogeneous tugboats to sequential berthing and unberthing operations, respecting critical factors such as towing capacity, sailing times, and idle requirements between consecutive jobs.

This study formulates a multi-objective MILP model designed to minimize two primary objectives: total weighted turnaround time for vessels (reflecting berth efficiency) and total weighted tugboat lateness for both inbound and outbound operations (capturing responsiveness and scheduling effectiveness). The formulation explicitly includes constraints for berth capacity, vessel arrival precedence, and feasible tugboat-task pairings. For the stochastic extension, a two-stage stochastic MILP is developed, where initial berth and tug decisions are made in the first stage, prior to the realization of uncertainty. Subsequent operational adjustments are then made in the second stage through scenario-specific slack variables. This stochastic model explicitly incorporates variability in ship arrival times and tugging durations, based on a finite set of discrete scenarios derived from empirical distributions. This approach allows for proactive anticipation and reactive adjustments, aiming for minimal recovery costs. All activities are represented in a continuous time-space diagram, and spatial and temporal precedence among vessels are rigorously modeled through binary decision variables. [1, 2].

Results

The model was extensively validated through a series of synthetically generated, realistic instances, consistently demonstrating its capability to produce feasible, conflict-free schedules that align with real-world operational constraints. Regarding the deterministic model performance, the model consistently delivered structurally sound and operationally coherent schedules. In most scenarios, tugging delays were entirely eliminated, with the objective primarily composed of the Total Weighted Turnaround Time (TWTT). Small and moderately sized instances converged to proven optimality in under 30 seconds. Even the most computationally intensive instance (Instance 8), which involved over 550,000 constraints and 270,000 binary variables, was solved to optimality in approximately 42 minutes (2518.37 seconds).

A sensitivity analysis of the deterministic model demonstrated its robustness and flexibility across varying operational conditions. Berth allocation cost was identified as the most sensitive component of the objective function, highlighting the critical role of berth time optimization in overall port efficiency. Tugboat availability emerged as a critical driver: increasing tugs from one to three yielded substantial reductions in total cost and turnaround time, with diminishing returns observed for more tugs. A comparative analysis between deterministic and stochastic models revealed distinct behaviors. The stochastic model consistently yielded higher objective values, often by a factor of two or more, primarily due to the increased TWTT, which incorporates the expected cost of uncertainty and the need for proactive/reactive adjustments. While deterministic schedules had zero tugging lateness, the stochastic model incurred small but deliberate lateness, mainly in inbound tug operations, as a result of conservative staggering and serialized tug usage to preserve feasibility under uncertainty. Structural shifts were observed: berth allocations in the stochastic solutions were deliberately dispersed to create buffer zones, and tug assignments often shifted to avoid compact sequencing, hedging against potential delays. The stochastic model imposed a heavy computational burden, with solver times increasing dramatically from under one second in deterministic runs to hundreds or even over a thousand seconds (e.g., from 0.34s to 360.24s in Instance C).

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New Integer Programming Models for the Multi-Depot Vehicle Routing Problem with Inter-Depot Routes

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Problem Description

The increasing complexity of real-world logistics systems has led to the development of advanced routing models that go beyond the classical Vehicle Routing Problem (VRP). Among these, the Multi-Depot Vehicle Routing Problem with Inter-Depot Routes (MDVRPI) stands out due to its flexibility, realism, and practical relevance to complex, real-world distribution systems. In this problem, a fleet of vehicles is based at multiple depots, and unlike in traditional Multi-Depot VRPs, vehicles are allowed to travel between depots during their routes, enabling them to replenish or offload goods at alternative depots, operating as intermediate facilities.

A solution to the MDVRPI involves the generation of rotations, which consist of sets of routes assigned to each vehicle that start and end at the same depot. These rotations may include open routes (starting and ending at different depots), and closed routes (within the same depot). Vehicles must serve a set of geographically distributed customers, subject to operational constraints, such as vehicle capacity and maximum rotation duration, while ensuring that all customers are visited.

Research Gap and Contributions

The MDVRPI introduces a level of operational realism that is essential for modern supply chain management. Traditional VRP formulations, even those involving multiple depots or intermediate facilities, do not adequately model the fluid roles that depots can play in practice. In contrast, the MDVRPI allows depots to serve not only as start/end points for routes but also as replenishment nodes along the way.

Despite its practical importance, the MDVRPI remains underexplored in the field of Operations Research, particularly from the perspective of exact mathematical programming. Most approaches in the literature rely on heuristics or matheuristics to handle small to mid-sized instances. For example, Muter et al. solved small-size instances using branch-and-price methods, whereas Ramos et al. proposed a decomposition-based matheuristic capable of solving large-scale instances.

This research aims to address this gap by proposing and comparing new compact Mixed Integer Linear Programming (MILP) formulations for the MDVRPI, adapted from the compact models studied by Bektaş et al. for the MDVRP, to posteriorly enable straightforward, off-the-shelf use by practitioners.

Methodology

The methodological foundation of this work is based on introducing the concept of replica nodes for depots, i.e., splitting the double function of a depot as a start and end point, or as an intermediate facility. This approach involves duplicating each depot per each other depot, effectively transforming the MDVRPI into a MDVRP. Such a structure facilitates the adaptation of formulations originally for the MDVRP to the MDVRPI, leading to the possibility of using two-index formulations.

In the new proposed formulations, decision variables represent the travel arcs between customers and depots and their replicas, vehicle loads, and currents to differentiate rotations of different depots. To ensure its feasibility, the model includes capacity constraints, ensures each customer is visited exactly once and limits the total duration of each rotation. Sequencing and load continuity are

enforced using subtour elimination constraints, either single-commodity flow-based (SCF) or Miller-Tucker-Zemlin (MTZ) constraints, adapted to account for possible inter-depot travel. Furthermore, path elimination constraints are implemented to prevent infeasible routes that do not return to the original depot. To enforce path elimination constraints, the node (NODE) and arc current (ARC) formulations proposed by Bektaş et al. are used in the models. These formulations assign a unique "current"(similar to an electrical current) to each depot, enabling unique route identification for each one. This current-based approach complements the replica-node structure by ensuring depot consistency across customer sequences. The models were implemented in Python using the Visual Studio Code development environment and formulated with the PuLP optimization library, which interfaces with the commercial solver Gurobi.

Given that the SCF+ARC model had the best computational performance among the formulations considered, a subset of its constraints is presented below as a representative example. The left-hand side displays the constraints of the SCF component, which enforce flow conservation at each network node and impose capacity limits, through the variables f_{ij}. On the right-hand side, the ARC component includes constraints that link the initial arcs of each rotation to the corresponding depot current and ensure the continuity of this current flow along the entire rotation, as modeled by the variables g_{ij}.

$$\sum_{\substack{i \in V \\ i \neq c}} f_{ic} - \sum_{\substack{j \in C \\ j \neq c}} f_{cj} = d_c, \forall c \in C \quad (1)$$

$$f_{ij} \leq (Q - q_i) x_{ij}, \forall i \neq j \in C \quad (2)$$

$$f_{ij} \geq d_j \times x_{ij}, \forall i \neq j \in C \quad (3)$$

$$f_{ij} \leq Q \times x_{ij}, \forall i \in D \cup R,\ j \in C \quad (4)$$

$$f_{ij} \geq d_j \times x_{ij}, \forall i \in D \cup R,\ j \in C \quad (5)$$

$$g_{di} = i_d \times x_{di}, \forall d \in D,\ i \in C \quad (6)$$

$$g_{id} = i_d \times x_{id}, \forall d \in D,\ i \in C \quad (7)$$

$$\sum_{j \in V} g_{ji} - \sum_{j \in V} g_{ij} = 0, \forall i \in C \quad (8)$$

$$\sum_{j \in C} g_{ji} - \sum_{j \in C} g_{ij} = 0, \forall i \in R \quad (9)$$

$$x_{ij} \leq g_{ij} \leq |D| \cdot x_{ij}, \forall i, j \in C \cup R \quad (10)$$

Results

The formulations were validated across benchmark instances, confirming their correctness through result parity with those reported by Muter et al. and Ramos et al.. Among the four tested formulations - SCF+Arc, SCF+Node, MTZ+Arc, and MTZ+Node - the SCF+Arc model consistently delivered the best performance in convergence time, optimality gap, and solution quality. All 22 benchmark instances were re-evaluated using this model, with a fixed runtime of 10800 seconds (3 hours), and a single thread.

The original benchmarking instances from the literature, introduced by Crevier et al., with problem sizes varying from 48 to 288 customers, and 3 to 6 depots, were adjusted to have 25 customers, a demand of 50, and a maximum rotation duration of 450 seconds (e.g., a1-25-50-450). Across these adjusted instances, the proposed model achieved 15 optimal solutions (CPU $\leq$ 10800s), out of 22 total instances. It outperformed the 3 optimal solutions achieved by both Muter et al. and Ramos et al., providing 12 more optimal solutions. Even when not optimal, our model reached better upper bounds and lower CPUs, leading to best known solutions (BKS) across all tested cases. Future work will focus on evaluating the model on instance sets with 40 customers and on the original benchmark sets.

	This work		Ramos et al. (2020)		Muter et al. (2014)	
	Optimal	**BKS**	**Optimal**	**BKS**	**Optimal**	**BKS**
All Instances (22)	15	22	3	4	3	7

Tabela 1: Comparison of Optimal and Best Known Solutions, over 22 instances.

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Methods for Bi-objective Routing and Districting Problems

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Problem Description

Districting and routing are critical components of modern logistics and transportation systems, especially in the context of e-commerce, smart cities, and global supply chains. This study addresses the Capacitated Vehicle Routing and Districting Problem (CVRDP), an extension of the Capacitated Vehicle Routing Problem (CVRP), which involves partitioning customers into districts and determining optimal routes from a central depot. Each vehicle, with a uniform capacity, serves a single district and returns to the depot after visiting its assigned customers. Unlike the traditional CVRP that focuses primarily on minimising travel distance, the CVRDP incorporates districting considerations such as workload balance and minimizing the number of districts, making the problem more complex. This work tackles the bi-objective nature of CVRDP by aiming to minimise total travel time and the average dispersion of districts.

To address the CVRDP, the paper presents a novel exact solution method that integrates districting and routing decisions using Mixed-Integer Linear Programming (MILP) formulations. Four compact models are explored—aggregated and disaggregated versions of the Improved Miller-Tucker-Zemlin (MTZ) and Single Commodity Flow (SCF) models—for their effectiveness in subtour elimination. The augmented ϵ-constraint [1, 2] method is applied to handle the bi-objective optimization, and benchmark instances are used for computational testing.

Formally, the problem CVRDP consists of finding a p-partition of the set of nodes, that minimises the total travel time and minimises the average dispersion of the districts. For every district, a vehicle departs from and finishes at the depot. Each customer must be a part of a single route and visited exactly once. The demand of a customer must be fulfilled and the vehicles have a limited capacity for transportation. The problem follows some assumptions. Each customer has a non-negative known demand, d_i, with $i \in C$. For each pair of nodes, the travel time, t_{ij}, is known, with $i, j \in V$ and $t_{ij} \in \mathbb{Z}$. The travel time is the same in both directions. As a result, the travel time matrix, consisting of the travel times between all pairs of nodes, displays symmetry. The fleet of vehicles is homogeneous and the total demand allowed per route must be less than or equal to the capacity of each vehicle, Q. Only one vehicle per route is possible. Each district and route in the problem are interchangeable, meaning that each district corresponds to a single route, and each route is associated with a district.

Relevance of the Problem

Companies can benefit from incorporating strategies that combine both districting and routing in their operations. As a result, companies are able to streamline their operations as well as reduce costs and improve service levels. Districting and routing problems are characterised by their multi-objective nature. Finding solutions to these problems requires finding a balance between multiple criteria. Among these criteria, one of the most common is the cost, which is directly associated with the number of vehicles employed and the distance they travel. District compactness, district partition dissimilarity, profit equity, and workload balance are other possible criteria to consider for the districting problem. By carefully managing these criteria, companies can make informed decisions to improve resource allocation, distribution efficiency, and overall cost-effectiveness in their operations.

Even though the field of districting and routing has been extensively explored, the simultaneous application of both approaches at the same level has not yet received considerable attention. Traditional routing models often overlook the geographical distribution of delivery areas, leaving systems vulnerable to disruptions like traffic congestion or adverse weather conditions. By incorporating compact districts, our approach enhances resilience to such disruptions, improving customer service, satisfaction, and reducing carbon emissions. For example, during traffic congestion, only deliveries within that compact district would be impacted, minimising disruptions compared to scenarios with overlapping routes. In addition, compact districts facilitate operational planning and have potential benefits for employees who often prefer to operate in specific geographic zones.

Methodology

To tackle this problem, four techniques are presented. These are the aggregated and disaggregated (i) Improved Miller-Tucker-Zemlin (hereafter MTZ) constraints (see [3]) proposed by Desrochers and Laporte [4] and (ii) the Single Commodity Flow model by Gavish and Graves (hereafter SCF) [5]. To transform the disaggregated into the aggregated model, one must sum the variables and constraints across all districts, l. These submodels besides preventing subtours, also guarantee the capacity constraints. The main advantage of utilising these particular techniques is that they provide compact models that are readily integrable into general-purpose solvers.

The augmented ϵ-constraint AUGMECON2 [2] approach was selected to solve the CVRDP. The purpose of the method is to find all Pareto optimal solutions, also called non-dominated vectors, or outcome vectors in the objective space. The main advantage of this approach is that it allows us to present multiple options to the decision-maker, offering a broader perspective on the trade-offs between objectives. Sequential optimisation, on the other hand, would not provide this flexibility, as it typically restricts the objective space by solving one problem after the other, potentially overlooking valuable alternatives. The enhanced version guarantees that the solutions found are non-dominated. The main idea behind this method is to convert a multi-objective problem with n_k objective functions into a single-objective problem. The method transforms all the objective functions, i, into constraints, except for one, with $i = 1, 2, ..., n_k$. In a minimisation or maximisation problem, these transformed objective functions are restricted by an upper or lower bound, respectively, denoted as ϵ_i for the objective function i, $i = 1, 2, ..., n_k$. The augmented version also incorporates in the objective function a component of the remaining objectives, referred to as *perturbation* to guarantee the solutions are non-dominated.

Results

The objective is to compare the performance of the algorithm proposed using the different modelling approaches for the subtour elimination. In the first phase, smaller instances with 15 customers are used to compare the results. The SCF-A model delivers the worst results across all metrics and is therefore excluded from the next phase. The second phase focuses on evaluating the performance of the best models using instances with 25, 50, and 100 customers. Table 2 summarizes the results. The third phase examines the impact of different parameters on the results. Lastly, the fourth phase analyses the results considering only a single objective function. By conducting a multiple-phase analysis, we gained insights into both the models' performance on small instances and their potential for handling larger, more complex problem instances. Based on the computational experiments conducted using adapted instances from the literature, it was concluded that, in this bi-objective model, the SCF–D clearly outperformed the remaining models. This conclusion was reinforced by the analysis of the variation of districts.

Tabela 2: Computational results - instances with 25, 50 and 100 customers

Average	25 customers			50 customers		100 customers	
	MTZ–A	MTZ–D	SCF–D	MTZ–A	SCF–D	MTZ–A	SCF–D
Average Total Time (s)	4,628	5,576	**621**	11,582	**9,485**	*	**36,000**
Average Nodes used	156,710	181,277	**3,806**	23,976	**4,854**	*	**1,270**
Average Solve time/iteration (s)	1,174	1,565	**184**	3,495	**3,351**	*	**14,400**
Average Gap (%)	3.0	3.3	**0.0**	35.8	**32.7**	*	**62**

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Melhorar a Eficiência dos Cuidados Domiciliários: uma abordagem heurística

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Descrição do problema

O problema em estudo consiste na otimização das rotas e horários para a prestação de cuidados domiciliários aos utentes de uma organização de apoio social, com o objetivo de minimizar os tempos de trabalho não efetivo (tempos de viagem + tempos de espera) das equipas de cuidadores enquanto se procura também maximizar a continuidade de cuidados aos pacientes, ou seja, a manter a lealdade cuidador-paciente. Este tipo de problema é classificado como um Problema de Roteamento e Planeamento de Cuidados de Saúde ao Domicílio (HHCRSP).

A complexidade do HHCRSP está na necessidade de planear as rotas dos cuidadores, alocando visitas a cada cuidador e agendando a ordem em que estas devem ser efetuadas, de modo a respeitar as janelas temporais específicas de cada visita. No caso de estudo, os cuidados prestados incluem serviços como higiene pessoal, limpeza doméstica, recolha e entrega de roupa lavada e distribuição de refeições, com durações de serviço variadas e uma de três janelas temporais associadas - manhã, tarde ou uma última associada exclusivamente ao serviço de entrega de refeições. Todos os cuidadores estão habilitados a prestar qualquer tipo de serviço a qualquer utente, não existindo questões de compatibilidade.

A organização do caso de estudo valoriza a continuidade de cuidados intra-semanal, levando à necessidade do planeamento de serviços para vários dias em simultâneo. Todos estes aspetos, tornam o problema altamente desafiador do ponto de vista computacional e logístico. Este caso de estudo foi previamente abordado em [1] utilizando um método exato, não tendo sido encontrada uma solução viável para todos os dias da semana dentro de um tempo computacional aceitável. Torna-se então necessário recorrer a abordagens heurísticas capazes de lidar com esta complexidade, procurando soluções viáveis e eficazes dentro de prazos aceitáveis.

Relevância do problema

A prestação de cuidados de saúde e apoio domiciliário está a tornar-se cada vez mais central na resposta aos desafios colocados pelo envelhecimento da população. Em Portugal, existem atualmente 188 idosos (65 anos ou mais) por cada 100 jovens (até aos 14 anos), colocando o país entre os mais envelhecidos da União Europeia. Além disso, 38,2% da população idosa do país encontra-se em situação de dependência, o que agrava a pressão sobre o sistema de saúde e os serviços sociais [2]. Como referido em [3], muitos idosos preferem permanecer no conforto das suas casas em vez de recorrer a lares, tornando essencial a existência de soluções eficazes de apoio domiciliário.

Neste contexto, organizações de apoio social, como a do caso de estudo, desempenham um papel fundamental ao garantir cuidados diários a utentes idosos e/ou com mobilidade reduzida. No entanto, estas instituições operam frequentemente com recursos escassos e orçamentos limitados, o que torna a otimização do planeamento e da logística dos serviços um fator crítico para garantir a sustentabilidade das operações. O HHCRSP tem vindo, por isso, a ganhar crescente atenção na literatura científica, refletindo a necessidade de modelos matemáticos e algoritmos que apoiem a tomada de decisão nestes contextos.

Metodologia

Para resolver o problema, foi adotada uma abordagem heurística greedy, baseada nos métodos apresentados em [4]. A metodologia consiste na adaptação e aplicação de duas variantes heurísticas: ConstructbyCaregiver (CxC), que prioriza a eficiência temporal, e ConstructbyUser (CxU), que dá prioridade à continuidade de cuidados. Ambas as heurísticas foram ajustadas para refletir as particularidades do caso de estudo, como a existência de apenas três janelas temporais e a existência de serviços adicionais.

A heurística CxC constrói as rotas para cada equipa para cada dia, por ordem cronológica. Diferente de [4], onde se começa pela equipa com menor carga de trabalho, a versão usada neste caso de estudo não segue essa prioridade, pois o equilíbrio de carga horária não é o foco. Essa alteração permite ao modelo obter soluções com menos equipas e maior continuidade nos cuidados. Para cada equipa, seleciona-se a próxima tarefa a ser atribuída com base num de dois critérios (escolhido aletoriamente): a tarefa que pode ser iniciada ou terminada mais cedo. Se a atribuição de uma tarefa implicar uma troca de cuidadores, é aplicada uma penalização para evitar mudanças frequentes na equipa que atende o mesmo utente.

A heurística CxU adota uma abordagem diferente, onde a prioridade é garantir a continuidade de cuidados. Para tal, as rotas são construídas para todos os dias e todas as equipas em simultâneo, sendo cada rota construída por ordem cronológica. As tarefas são atribuídas com base num critério de prioridade que analisa o horário de início ou término de cada tarefa, inserindo aqui a componente de aleatoriedade. As equipas são selecionadas de forma a minimizar a rotação de cuidadores, sendo blocos de visitas a um mesmo utente agendados simultaneamente para a equipa que puder realizar o máximo delas. Visitas que gerem longos tempos de espera são evitadas para reduzir o tempo não efetivo. Para que este fator não interfira com a espera normal entre as tarefas da manhã e da tarde, nesta versão, a heurística é efetuada em duas fases: primeiro para as tarefas da manhã e depois para as da tarde.

A construção das soluções é feita de forma iterativa, respeitando os constrangimentos definidos e avaliando as soluções com base numa função objetivo que equilibra o tempo não-efetivo total e o número de tarefas não agendadas. O método CxC foi também implementado com uma outra função objetivo, onde o tempo de espera não é considerado, dando origem à variante CxC_{tt}. A alteração da função objetivo para o método CxU não conduzia a mudanças significativas nos resultados, pelo que apenas uma variante deste método foi considerada, usando a nova função objetivo. A introdução da aleatoriedade em ambas as heurísticas permite explorar múltiplas soluções ao longo das iterações.

Resultados

Os resultados que se seguem correspondem à melhor solução obtida para cada método. Na Figura 1, podemos ver que, para segunda e terça-feira e para o fim de semana, os resultados obtidos em [1] são os melhores. No entanto, os métodos CxC_{tt} e CxC_{ne} conseguem obter rotas para todos os dias da semana, com tempos de viagem menores do que na solução original. Para CxC_{tt}, a redução total foi de 67 min e para CxC_{ne}, de 2.5 min. É de salientar que, apesar do método CxC_{ne} obter uma redução no tempo de viagem semanal, para alguns dos dias da semana, os tempos são maiores do que os da solução original. O método CxU apresenta os piores tempos, representando um aumento de 172.5 min face à solução original. Quanto à continuidade de cuidados, obteve-se uma média de 1.43 equipas por utente para o método CxC_{tt}, 1.54 para o CxC_{ne} e 1 para o CxU. Neste aspeto, apenas o CxU se compara à solução original, também com apenas 1 equipa por utente. Isto faz sentido sendo que este método tem um maior foco na continuidade de cuidados. No fim de semana, o número de visitas é muito reduzido e apenas uma equipa é utilizada, pelo que não é surpreendente que a redução ou o aumento no tempo de viagem para esses dias seja mínimo.

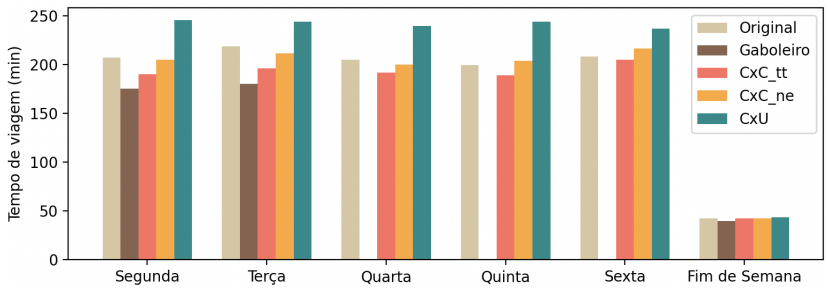

Figura 1: Tempo de viagem por dia da semana para cada um dos métodos

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Optimization and economic analysis of energetic systems in a wastewater treatment plant

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Problem description

The Gaia Litoral wastewater treatment plant (WWTP), operated by SIMDOURO in the municipality of Vila Nova de Gaia, faces growing energy demands, due to a progressive increment of the population in this region, which results in an increase in the intake of organic matter. The WWTP has the capability of producing and storing biogas, a renewable energy source that can be used in a combined heat and power co-generator (CHP) to produce electricity and heat. The available biogas often exceeds the energetic needs of the plant to function. In spite of this, a significant share of biogas is flared, contributing to waste and green house gas emissions.

Additionally, the plant will be installing a photovoltaic system, which will create an opportunity for enhanced energy efficiency. Due to the inherent intermittency of photovoltaic energy and the lack of storage on this front, the optimal management of energy flows becomes complex. Without proper optimization, excess biogas may continue to end up being flared and solar energy may go unused by the plant, resulting in the continuous necessity to purchase energy from the general grid. The WWTP also has the ability of selling excess energy back to the grid or, given the close proximity with other infrastructures of the same company, create a Renewable Energy Community (REC), allowing the excess energy produced to be donated to other plants nearby.

This study intends to show the possibilities for energy optimization in a WWTP by creating optimization models and comparing the outcomes with the real data from 2023.

Problem relevance

Wastewater treatment plants (WWTP) are one of the primary consumers of energy in modern societies [1]. The transition to decentralized and renewable energy sources is a cornerstone of EU energy and climate policy, with WWTPs identified as prime candidates for this transformation [2, 3]. The need for better management of energy sources in WWTPs has been widely documented and addressed in numerous studies [4, 5, 6, 7]. However, due to the nature of each WWTP, each case is different. The location of the plant, as well as the energy sources at their disposal, vary from case to case. Thus, the necessity to further investigate and tackle new case studies is always paramount.

Methodology

As stated previously, the WWTP has biogas and photovoltaic production. Historical data from 2023 for biogas and internal energy consumption was retrieved from the internal database of the company. Since photovoltaic will only be installed in a near future, the dataset for this part was simulated. Irradiance data from 2023 for the location of the WWTP was retrieved via the Solcast API [8], which allowed for the estimation of the potential production that the system would have had in 2023.

A simulation-based, rule-driven optimization approach was implemented in Excel using Visual Basic for Applications (VBA). This ensured accessibility and practical use in operational environments.

The main objectives defined were to reduce the costs, reduce the amount of biogas flared in the torch, and increase the self-sufficiency ratio of the WWTP over one year. The first two objectives were analyzed through dedicated simulations, whilst the third one was analyzed as a byproduct of the other two.

The plant was modeled as a multi-energy system. The WWTP had to always fulfill their energy needs. This could be achieved by utilizing the renewable energy sources or by purchasing energy to the grid. When the produced energy was higher than the demand, it could be sold to the grid or donated to a REC. Four optimization scenarios were designed:

1. Multi-objective simulation, only considering the production of biogas. This intends to be a direct comparison to the year of 2023;

2. Multi-objective simulation, considering both biogas and photovoltaic production. The model tries to compromise between both objectives;

3. Minimization of purchased electricity, considering both renewable energy sources;

4. Minimization of flared biogas, considering both renewable energy sources.

The results of each simulation were analyzed by calculating the self-sufficiency ratio (SSR), the wasted biogas ratio and the total cost of purchased electricity.

Results

The simulation results demonstrated significant improvements across all optimization scenarios. The output suffers substantial changes from the presence of PV production and depending on the approach taken for simulation.

According to data from 2021 until the beginning of 2024, the WWTP was unable to achieve SSR above 72%, with the average being close to 50%. However, with the first simulation model, it was able to achieve an average SSR of 74%. When also considering PV production, the numbers were bumped up to over 91% in the second simulation, with no wasted biogas and 70 thousand euros in electricity savings.

The third simulation narrowly missed out on avoiding the purchase of electricity, with a 99,46% SSR. However, the wasted biogas ratio was the highest at over 25%. Lastly, the final simulation achieved over 91% SSR, with 162 thousand euros in electricity savings and zero wasted biogas.

Overall, these findings confirm earlier studies which emphasized the economic and operational advantages of coupling renewable energy sources with optimized control strategies in WWTPs.[9, 10]

After completing the dissertation, the project continued to be developed in a business environment. The starting point for further development was the simulation with the best self-sustainability ratio. In order to extract maximum value from the optimization process, greater focus was placed on the economic aspect of the results, concentrating efforts on minimizing the overall energy costs of the Gaia Litoral WWTP. Following this development, it is intended to incorporate machine learning models to predict the WWTP's internal consumption and biogas production based on historical data. The final step in the development of this tool will be to expand its use to the rest of the company's infrastructures.

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Optimisation Model for Demand-Side Flexibility in the Agricultural Sector

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Problem description

The energy transition is essential to reduce greenhouse gas emissions, and this requires the large-scale deployment of decentralised renewable energy production and a greater flexibility from the electricity grid, i.e. the ability to adjust production and consumption in real time. Traditionally, the supply side has been responsible for providing this flexibility. However, it is imperative to explore demand-side flexibility options, particularly in sectors with potentially adaptable load profiles, such as agriculture [1].

Efficient management of energy loads in agriculture is a complex challenge, arising from the need to adjust energy-intensive operations to meet stringent service levels, such as irrigation systems, motors, greenhouse air conditioning and refrigeration systems, while considering the intermittency inherent in renewable sources [2]. While existing optimisation models address load management in industrial or residential contexts, they often neglect the specificities of agriculture. These include strict operational constraints (e.g. irrigation schedules, minimum water storage levels) and heterogeneity of loads (e.g. type of control) [3].

The aim of this work is to develop a mixed-integer linear programming (MILP) optimisation model that comprehensively captures demand-side flexibility in the agricultural sector by coordinating shiftable loads, local renewable generation, energy storage and grid procurement under time-varying tariffs to minimise total energy costs.

Problem relevance

MILP models have been extensively adopted for the scheduling of shiftable loads in conjunction with storage assets. However, despite the extensive research that has been conducted on MILP-based energy management for buildings and microgrid communities, its tailored application to farm operations remains underexplored. This is because farm operations involve a diverse range of equipment which present unique scheduling opportunities [4]. Furthermore, although a few studies have introduced cost-minimisation objectives via MILP [5], they have not incorporated a quantitative indicator to measure flexibility, i.e., the amount of energy that is shifted or curtailed over the planning horizon.

The proposed framework makes three innovative contributions: firstly, it involves the development of an optimisation model for a relatively unexplored sector – agriculture; secondly, it is grounded in real case and on-site data monitoring using IoT sensors and the Shelly Smart Control app; and thirdly, it quantifies energy flexibility indicators adapted from other sectors.

Methodology

This section describes the methodology employed to optimise farm-scale energy management via a MILP framework, implemented in AMPL with a one-week control horizon. The methodology employed is comprised of three phases. First, the system is characterised, and high-resolution load profiles and controllable actions are established. Second, the mathematical model formulation is to be written, and the MILP model is formulated in AMPL. Third, the optimisation outputs are processed to extract dispatch schedules and to compute the flexibility indicators. This procedure demonstrates our key contributions and provides quantitative metrics illustrating how load shifting directly drives cost reductions.

The model concurrently administers four primary energy streams: on-site renewable generation, controllable and non-controllable loads, battery storage, and grid exchange. This enables the minimisation of total energy cost and the maximisation of self-sufficiency (SS) and self-consumption (SC). The photovoltaic output can be dispatched directly to loads, stored in the battery, or exported to the grid. The battery, in turn, may charge from either the PV system or the grid and discharge to serve all loads. Controllable loads include irrigation systems, water pumps, a washing machine, a water heater, pumps from a wastewater treatment plant (WWTP) and a refrigeration chamber.

The MILP framework incorporates the following variables: load controls capturing on/off and shifted operations of shiftable and thermal loads; battery state-of-charge capturing charging and discharging dynamics; renewable production; and electricity imported from the grid. All these elements are subject to energy-balance equations, equipment-specific operational limits and tariff and demand-response constraints. Furthermore, a flexibility indicator has been developed based on Li et al. [6], to quantify the overall system flexibility and the individual contribution of each load j:

$$F_{\text{Total}}(\%) = \sum_{j} \frac{E_{\text{shifted},j}}{E_{\text{Total}}} \times 100, \tag{11}$$

Results

The optimisation model was applied to a real agricultural context with the aim of minimising energy acquisition costs while enhancing SC and SS. Two scenarios were analysed: a baseline case with non-optimised operation with fixed load patterns and real-time load profiles, and an optimised case with intelligent scheduling of flexible and interruptible loads based on electricity prices and PV availability. The findings indicate that the optimised scenario results in a reduction of 15.36% in total energy expenditure when compared to the baseline scenario.

The optimised case demonstrates a decline of 5.00% in SC in comparison with the baseline case. This is substantiated by a decline in total energy consumption of approximately 200 kWh/week, attributable to a smarter management of loads such as the refrigerator chamber. This approach has curtailed the compressor operation without compromising temperature boundaries, leading to a slight decrease in the SC index. Nevertheless, there was an improvement of 11.03% in SS, which reflects improved alignment between generation, storage, and consumption. Regarding flexibility metrics, 38.74% of total consumption was successfully shifted. The most flexible loads were the pivot irrigation system (14.99%), the pool pump (9.65%) and the refrigerator chamber (8.27%). A further simulation showed that the injection of excess energy generated into the grid may yield a profit of 18.5 €/week.

The findings of this study demonstrate that intelligent load management has the potential to reduce energy costs and enhance efficiency in agriculture, thus reinforcing the role of farms as active participants in the broader context of the energy transition.

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Balanceamento de Postos de Montagem de Sofás: Uma abordagem de Otimização

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Descrição do problema

Os sistemas de fabrico atuais devem adaptar-se à constante mudança do mercado, impulsionada por flutuações na procura e crescente necessidade de customização, requerendo linhas de montagem aptas.

A empresa alvo desta investigação é uma produtora de sofás, e um importante interveniente da indústria de mobiliário, que enfrenta dificuldades na otimização do fluxo de trabalho dos postos iniciais (1 ao 6) de uma das suas linhas de montagem. O desafio reside na alocação eficiente das tarefas aos postos, condicionada pela elevada variabilidade dos tempos de execução e incerteza intrínseca ao processo de montagem.

O processo de montagem possui várias linhas de montagem dispostas em paralelo, sendo apenas estudado o balanceamento de uma delas. A linha em questão dedica-se à montagem manual de um modelo de sofá, apresentando um fluxo em linha reta básico, e opera com recurso a um tapete logístico a velocidade constante. Os postos estão dispostos sequencialmente, cada um composto por um único espaço de trabalho.

O modelo de sofá produzido subdivide-se em diferentes módulos e a montagem destes segue uma sequência fixa, pré-estabelecida e rigorosamente respeitada. O posto de trabalho 1 tem a particularidade de não estar ligado ao tapete logístico e apenas tratar um dos módulos, designado por "Conjunto de Laterais". No que concerne à mão de obra, os operadores estão fixos e afetos a um e somente um posto de trabalho.

Dado o facto da montagem ser totalmente manual, é notório a clara influência de intervenção humana no desempenho da linha de montagem. Assim, a diversidade de competências dos operadores, aliada a aspetos como a fadiga, a motivação ou o ritmo de trabalho, podem contribuir para uma grande variabilidade nos tempos de execução das tarefas. Essa variabilidade constitui um obstáculo significativo à eficiência operacional da referida linha. Além disso, a falta de visibilidade de dados em tempo real compromete a monitorização e otimização do processo, dificultando a identificação de atrasos ou gargalos. Paralelamente, a inexistência de dados históricos compromete o acesso a registos fiáveis dos tempos de execução, o que inibe a perceção de possíveis variações nesses tempos e, consequentemente, acentua a incerteza.

O principal objetivo do estudo é a integração de uma abordagem de otimização que permita balancear os 6 postos de montagem, minimizando o tempo de ciclo e incorporando a incerteza do processo. A solução de balanceamento visa melhorar a produtividade e eficiência operacional pela atribuição equitativa da carga de trabalho entre os postos, eliminando os gargalos existentes e evitando a subutilização de recursos.

Relevância do problema

Embora tenham sido propostas inúmeras aplicações de otimização robusta no âmbito de balanceamento de linhas [1, 2], bem como na indústria de mobiliário, nomeadamente no planeamento de produção [3], até ao momento nenhum modelo de otimização robusta foi proposto para lidar com o balanceamento de linhas de montagem nesta indústria. No melhor conhecimento da autora, apenas Pinarbasi et al. [4] propuseram um modelo matemático de otimização aplicado ao problema de balanceamento de linhas numa indústria de mobiliário na Turquia. A existência de somente um

artigo científico reflete pouca exploração desta problemática no setor, o que representa um *gap* na literatura e, consequentemente, reforça a importância deste trabalho científico.
Do ponto de vista científico, as contribuições deste trabalho são: explorar modelos de programação robusta no balanceamento de operações de montagem de sofás, que considerem incerteza dos dados e minimizem o tempo de ciclo; elaborar dois modelos matemáticos, um determinístico e um robusto, combinando-os com a minimização do número de ferramentas via otimização lexicográfica; e comparar a abordagem robusta face à determinística em termos de estabilidade da solução e desempenho produtivo. Na dimensão prática, este estudo permite testar a adequação do modelo num contexto de fabrico real, usando dados reais.

Metodologia

Na literatura existente, vários estudos do *assembly line balancing problem* assumem os tempos de execução das tarefas determinísticos. Contudo, em ambientes reais de fabrico - especialmente nos altamente dependentes de mão de obra - as tarefas são sujeitas a diversos fatores de incerteza, como o nível de experiência e a motivação dos operadores [5]. Além destes, também a disponibilidade de recursos acentua a incerteza.
Para modelar a variabilidade dos tempos de processamento, vários autores recorreram a variáveis aleatórias baseadas em distribuições de probabilidade, tipicamente a distribuição normal [6, 7]. Em alternativa, outros utilizaram conjuntos *fuzzy*, cuja função de pertinência define uma distribuição de possibilidade associada a cada tempo de execução [8]. No entanto, neste caso, a escassez de dados históricos disponíveis impossibilita a aplicação destas abordagens porque se dependeria de uma função distribuição de probabilidade ou possibilidade conhecida à *priori*. Posto isto, adotou-se otimização robusta como metodologia para lidar com o problema sob incerteza. O problema foi formulado por meio de programação linear inteira mista, incorporando a relação de precedência entre as tarefas, a sequência de montagem dos módulos, bem como a alocação de ferramentas aos postos. Para tratar a incerteza nos tempos de execução, adotou-se uma abordagem de otimização robusta baseada no orçamento de robustez, conforme proposta por Bertsimas e Sim [9]. Esta técnica controla o grau de conservadorismo da solução através de um parâmetro que limita o número de coeficientes afetados por incerteza, permitindo soluções mais realistas do que a abordagem *minmax* tradicional. A validação das abordagens de solução foi assegurada por dados reais, fornecidos pela empresa, que envolve a alocação de 113 tarefas a 6 postos.
Como destacado por Ben-Tal e Nemirovski [10]:"Em aplicações do mundo real de Programação Linear, não se pode ignorar a possibilidade de que uma pequena incerteza nos dados possa tornar a solução ótima usual completamente irrelevante do ponto de vista prático". Deste modo, fica reforçada a importância de considerar robustez nos dados para lidar com os desafios associados a ambientes de fabrico reais.

Resultados

Os resultados estão em concordância com o expectável, indicando que o tempo de ciclo ótimo aumenta em função do aumento do orçamento de robustez e do desvio percentual máximo das tarefas em relação ao tempo nominal. O tempo de ciclo mínimo é assegurado pela versão determinística visto que não agrega incerteza. Por sua vez, a alocação das ferramentas é igualmente assegurada como objetivo secundário.

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Otimização Aplicada a uma Empresa de Processamento e Embalamento de Arroz

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Descrição do problema

A gestão eficiente do processo produtivo numa unidade de descasque, transformação e embalamento de arroz enfrenta diversos desafios operacionais e logísticos que se traduzem em pontos críticos. Estes problemas podem ser agrupados em três grandes dimensões: a matéria-prima (arroz), a estrutura produtiva e a capacidade de armazenamento. Relativamente ao arroz, surgem várias restrições que condicionam a organização da produção, tais como a disponibilidade e o arroz em si, que se organiza em variedade, estado de entrada e tipo de arroz. Por outro lado, a estrutura da fábrica, bem como a organização laboral da mesma, apresentam problemas que impedem a flexibilidade do mecanismo. Por fim, os limites de capacidade relacionam-se com questões de armazenamento de matéria-prima e produto já branqueado.

Assim, o trabalho desenvolvido apresenta dois modelos de otimização matemática para as áreas de planeamento de compras e planeamento de produção para uma empresa de transformação, embalamento e expedição de arroz. Procurou-se explorar, analisar e definir modelos matemáticos que respondessem a duas questões com grande ênfase a nível empresarial e, de seguida, foram delineados vários cenários de interesse empresariais e aplicados aos modelos matemáticos propostos. Para a área de planeamento de compras, queria-se definir qual o melhor planeamento de compras de forma a não haver roturas de *stock*, cumprindo com os requisitos logísticos do sistema produtivo, minimizando os custos globais de aquisição, preservando quantidades mínimas de *stock* e outros requisitos operacionais e financeiros. Para a área de planeamento de produção, desejava-se obter o melhor planeamento produtivo de forma a minimizar as perdas de negócio, garantindo que não há rotura de *stock*, reduzindo as mudanças de tipo de produto e cumprindo com os requisitos operacionais do sistema produtivo.

Relevância do problema

A otimização é um princípio fundamental na indústria, com aplicação direta na engenharia de processos, na gestão da produção e na eficiência económica das operações.

O estudo de modelos matemáticos para o planeamento das compras tem um elevado impacto nas empresas, pois permite reduzir custos e, consequentemente, minimizar compras de emergência, garantir disponibilidade de matéria prima, reduzindo as paragens de produção e mantendo os níveis de *stock*, aumentar o poder de negociação, reduzir o descontrolo financeiro, distribuindo os pagamentos a fornecedores ao longo do tempo, e evitar compras desnecessárias, reduzindo o desperdício de qualquer tipo de material necessário em aprovisionamento. Por sua vez, o estudo de modelos matemáticos para o planeamento de produção permite otimizar recursos, melhorando a utilização de maquinaria e mão de obra, reduzindo o tempo de paragens, havendo assim um aumento da produtividade, garantir o cumprimento de prazos de entrega, reduzir os custos de produção, evitando horas extra, melhorar a qualidade do trabalho, com processos mais controlados e menos improvisações, e facilitar decisões estratégicas, porque permite simular vários cenários e assim tomar decisões fundamentadas.

Deste modo, a otimização de processos revela-se como uma ferramenta fundamental para empresas dos setores produtivos. Para o negócio em estudo, a prioridade estabeleceu-se na análise dos tempos de compras com a disponibilidade financeira e no cumprimento de entregas de produto acabado,

tendo em conta as restrições da linha de produção. O conhecimento obtido deverá auxiliar na tomada de decisões, tais como redução de custos, controle de níveis de *stock*, programação de produção e calendarização de paragens.

Metodologia

Para este problema, propõem-se formulações em programação linear inteira mista, que serão resolvidas usando o solver CBC disponibilizado pela COIN|OR e usado no suplemento OpenSolver (https://opensolver.org/) integrado no Excel. Face às questões que foram levantadas, tornou-se necessário analisar o problema em duas formulações. Deste modo, foi definida a Formulação 1, referente à modelação do planeamento de compras; e a Formulação 2, focada no planeamento de produção.

Para ambas as formulações, foram criados cenários que procuraram simular situações que replicam ocorrências do dia-a-dia empresarial e fabril. Para a primeira formulação, os factores de maior variabilidade envolveram os dados da procura. Para a segunda formulação, foram consideradas variações na procura, no tempo de total de laboração e na operacionalidade fabril.

Resultados

As soluções obtidas através das formulações propostas mostram forte correspondência à realidade do planeamento de compras e do processo fabril, o que as torna ferramentas valiosas de simulação. A análise e a discussão dos vários cenários permitem estabelecer estratégias nas áreas de planeamento de compras, planeamento financeiro e planeamento de produção. Estas análises mostraram a importância da integração dessas componentes na eficiência operacional da empresa.

No âmbito do planeamento de compras, estas soluções trazem uma calendarização que aproveitam os períodos mais favoráveis de aquisição, permitindo assim comprar de forma a não ultrapassar a disponibilidade financeira mensal, respeitando também a capacidade física para receção de matéria-prima. Este planeamento anual permite dar estabilidade e ter uma capacidade de poder de decisão mais fundamentada e assertiva.

Relativamente ao planeamento da produção, as soluções estruturam o processo produtivo ao longo de todo o horizonte mensal, promovendo um sequenciamento produtivo que respeita todas as limitações operacionais do processo, procurando minimizar as perdas comerciais. Os vários cenários delineados permitem antecipar mensalmente o impacto de diferentes situações e identificar formas de as mitigar.

A utilização futura deste tipo de mecanismos em meio empresarial promove o desenvolvimento do mesmo, pois deverá favorecer a rentabilização do trabalho e do negócio, com forte impacto no desempenho global da empresa e nos índices de produtividade. Ainda assim, a adição de restrições na Formulação 1 que envolvam a gestão de fornecedores, ou a gestão de armazenamento de material subsidiário no que respeita à Formulação 2, seriam aperfeiçoamentos de elevado impacto.

Este trabalho evidencia que a aplicação de modelos de otimização matemática ao planeamento de compras e de produção, numa empresa de transformação e embalamento de arroz, contribui para a adoção de melhores práticas de gestão, revelando potencial para a sua transposição e aplicação a outros setores do processamento agroalimentar.

Sistema de aprendizado de máquina para a recomendação de métodos de otimização aplicado a problemas de dimensionamento de lotes com múltiplas plantas

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Descrição do problema

O problema de dimensionamento de lotes com múltiplas plantas é uma variação relevante do problema de dimensionamento de lotes capacitado (CLSP) que visa determinar as quantidades e os períodos de produção, estoque e transferência de produtos em várias instalações industriais com o objetivo de minimizar os custos da operação [1]. Formulado como um problema de programação inteira mista (MIP), torna-se um problema mais desafiador que o CLSP, dada a necessidade de transferências e de coordenação da produção entre plantas. Devido à complexidade NP-difícil [2], sua resolução exata é computacionalmente desafiadora para instâncias de grande porte, enquanto matheurísticas, como a *relax-and-fix*, apresentam-se como alternativas viáveis para a resolução desses problemas, mas com desempenho dependente da parametrização e das características das instâncias [3]. O desempenho dos métodos de resolução é também afetado quando, no uso cotidiano, as estatísticas dos dados se alteram ao longo de diferentes períodos.

Este trabalho apresenta o desenvolvimento de um sistema de recomendação baseado em aprendizado de máquina para a seleção de métodos de resolução em problemas de dimensionamento de lotes com múltiplas plantas. O sistema de recomendação utiliza um modelo de classificação *multi-label*, treinado para identificar, a partir das características das instâncias, os métodos mais adequados para a resolução de cada problema. Para a resolução dos problemas de otimização, foram avaliados métodos baseados em MIP, que incluem diferentes parametrizações da heurística *relax-and-fix* e a resolução exata utilizando um *solver* comercial (Gurobi).

Relevância do problema

O dimensionamento de lotes é um dos principais desafios no planeamento da produção [4], consistindo na definição das quantidades e dos períodos de produção de um produto, para atender à demanda ao menor custo possível, minimizando os custos de *setup*, produção e estocagem. Com o progresso na resolução de modelos MIP nas últimas duas décadas, tornou-se possível resolver modelos mais complexos [5], que melhor refletem a realidade das empresas. A variante do dimensionamento de lotes com múltiplas plantas é particularmente relevante em indústrias que operam a produção de maneira distribuída, onde o planeamento integrado pode levar a economias significativas por meio de especialização, redução de custos de transporte e melhor utilização de recursos. A inovação deste trabalho está na integração de aprendizado de máquina com métodos de otimização, permitindo uma abordagem adaptativa que seleciona a forma mais apropriada para resolver cada instância do problema com base em suas características. Essa proposta difere das abordagens tradicionais que aplicam parametrizações estáticas que são definidas *a priori*.

Metodologia

A metodologia aplicada no trabalho compreende as seguintes etapas: **i) Geração de instâncias:** foram geradas 600 instâncias aleatórias do problema CLSP com múltiplas plantas, utilizando um

método adaptado da literatura [6]. As instâncias apresentam diferentes números de plantas (2, 4, 6, 15, 20) e produtos (10, 60, 120). O horizonte de planeamento foi fixado em 12 períodos, assim como em [7]. **ii) Resolução dos problemas:** cada instância foi resolvida utilizando o *solver* Gurobi e parametrizações da heurística *relax-and-fix* baseada em partições temporais, configuradas com diferentes tamanhos de janela (w) e parâmetros de *overlap* (γ). **iii) Extração e seleção de características:** foram extraídas características estatísticas de cada instância, incluindo média, mediana, mínimo, máximo, desvio padrão, curtose e assimetria dos dados de custos de configuração, transporte, demandas e capacidades, tempos de produção e *setup*, além de demandas e capacidades. **iv) Definição das variáveis-alvo:** um parâmetro de tolerância (τ) foi utilizado para determinar a adequação de cada método de resolução, considerando métodos adequados aqueles cujas soluções estavam dentro de τ% do melhor valor da função objetivo encontrado. **v) Classificação *multi-label*:** um modelo de aprendizado de máquina baseado em uma cadeia de classificadores *random forest* foi treinado para prever a adequação de cada método a novas instâncias. **vi) Validação do modelo e avaliação de desempenho:** os resultados obtidos pela classificação das instâncias de teste resolvidas foram validados a diferentes níveis de tolerância (τ). Foram geradas novas instâncias para avaliação do desempenho do modelo de previsão em problemas inéditos.

Resultados

Os resultados obtidos destacam a eficácia do sistema proposto e indicam oportunidades de aplicações práticas em problemas de otimização recorrentes e com alta variabilidade nos dados. Não houve um método de resolução universalmente superior. O Gurobi apresentou a menor mediana de desvio relativo à melhor solução, enquanto métodos computacionalmente mais simples, como a *relax-and-fix* com apenas um período na janela de decisão, tiveram desvios maiores. Métodos complexos ofereceram melhor qualidade em tolerâncias baixas ($\tau = 0{,}1\%$), mas com tempos computacionais mais elevados, evidenciando um *trade-off* entre qualidade e eficiência.

Ao validar o modelo treinado, o sistema de recomendação alcançou uma precisão de 76,56% na recomendação de métodos para novas instâncias com $\tau = 0{,}1\%$, sempre superando todas as estratégias ingênuas, nas quais um único método seria aplicado para resolver todas as instâncias (a melhor precisão ingênua foi de 65,63% com o Gurobi). A análise SHAP (SHapley Additive exPlanations) [8] revelou que custos de *setup*, custos de transporte, número de plantas e curtose da capacidade foram os fatores mais influentes na seleção dos métodos. Por exemplo, instâncias com altos custos médios de *setup* e transporte tendem a beneficiar-se de métodos mais simples, que resolvem menos variáveis binárias por iteração, enquanto capacidades mais uniformes são favorecidas pela resolução com métodos mais complexos.

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