Proceedings of the 30th EURO Working Group on Locational Analysis Meeting

Jerez, Spain
17-19 September 2025

EWGLA
LOCATIONAL
ANALYSIS

UCA
Universidad
de Cádiz

REDLOCA
Spanish Network on Location Science

Proceedings of the 30th Euro Working Group on Locational Analysis meeting

Jerez de la Frontera, Spain
17-19 September 2025

PROCEEDINGS OF THE 30th EURO WORKING GROUP ON LOCATIONAL ANALYSIS MEETING

Edited by

Marta Baldomero-Naranjo

Carmen-Ana Domínguez-Bravo

Luisa I. Martínez-Merino

Juan M. Muñoz-Ocaña

Nicolás Zerega

ISBN: 978-84-09-72535-9

Contents

Welcome

Dear Locators,

Welcome to the 30th EWGLA meeting, held in Jerez de la Frontera, Spain, from 17 to 19 September 2025. The EURO Working Group on Locational Analysis has become a vehicle for communication among researchers focused on location and related topics worldwide. In particular, EWGLA meetings are regular events that allow researchers and practitioners to meet and discuss trends in location and related problems. The sessions address methods and models for theoretical and practical problems. In addition, EWGLA meetings combine a strong scientific program with a friendly atmosphere that encourages open exchange and collaboration.

This year, EWGLA meeting takes place together with the 14th International Workshop on Locational Analysis and Related Problems (IWOLOCA). IWOLOCA meetings are organized by the Spanish Network on Locational Analysis (REDLOCA) and the Location Group of the Spanish Society of Statistics and Operations Research (GELOCA). These workshops bring together national and international researchers working in the field of Location Science.

EWGLA meetings have been successful over the years, showing that locational analysis continues to spark interest among researchers. This year the meeting features 69 contributions covering a broad range of topics, from discrete location, over hub location and routing, to network design and a variety of interesting applications. The large number of speakers required us to have parallel sessions during the three days of conference. This edition brings together 84 participants from 14 different countries. This book compiles all accepted contributions for the conference. The abstracts are arranged in alphabetical order by the presenting authors' last name. Additionally, an author index is provided at the end of the book, detailing the page numbers where each author's contributions can be found. We hope that this compilation will serve as a valuable resource for all attendees and make a meaningful contribution that will enrich the scientific discussions throughout the event.

This meeting features the participation of three invited plenary speakers. We are honored by their participation and pleased to share this event with them. Prof. Burcu Balçik (Özyeğin University) will present her work related to location and transportation problems in Humanitarian Logistics. Prof. Anthony Papavasilou (National Technical University of Athens) will share with us his advances in an EU-wide power generation expansion problem including renewable energy targets. On the occasion of the 30th EWGLA meeting, prof. Vladimir

Marianov (Pontificia Universidad Católica de Chile) will present a personal retrospective about some important topics on Locational Analysis.

We would like to thank all those who contributed to the organization of this meeting. Especially, we wish to highlight the compromise and effort of the organizing committee. We would also like to acknowledge the scientific committee for their valuable contribution.
Finally, we would like to acknowledge the support of the EWGLA, the GELOCA, and the Spanish Agency of Research (AEI) through grants RED2022-134149-T funded by MICIU/AEI /10.13039/501100011033. We would also like to thank the following institutions of the Universidad de Cádiz: Facultad de Ciencias Sociales y de la Comunicación, Instituto Universitario para el Desarrollo Social Sostenible, Plan Propio UCA 2025-27 and Departamento de Estadística e Investigación Operativa. Thanks to their financial support, part of the organization of this meeting was possible.

We wish you an enjoyable experience at EWGLA 2025, both scientifically and socially.

Carmen-Ana Domínguez Bravo and Luisa I. Martínez Merino
Chairs of EWGLA 2025 Organizing Committee

Committees

Scientific Committee

Victor Blanco	Universidad de Granada	Spain
Giuseppe Bruno	Università di Napoli Federico II	Italy
Hatice Çalık	KU Leuven	Belgium
Sourour Elloumi	ENSTA Paris	France
Serena Fugaro	National Research Council of Italy	Italy
Boglárka Gazdag-Tóth	University of Szeged	Hungary
Ioannis Giannikos	University of Patras	Greece
Jörg Kalcsics	University of Edinburgh	UK
Bahar Kara	Bilkent University	Türkiye
Martine Labbé	Université Libre de Bruxelles	Belgium
Alfredo Marín	Universidad de Murcia	Spain
Luisa I. Martínez-Merino	Universidad de Cádiz	Spain
Stefan Nickel	Karlsruhe Institute of Technology	Germany
Olivier Peton	IMT Atlantique	France
Diego Ponce	Universidad de Sevilla	Spain
Justo Puerto	Universidad de Sevilla	Spain
Francisco Saldanha da Gama	Sheffield U. Management School	UK
Sibel Salman	Koç University	Türkiye
Anita Schöbel	Universität Göttingen	Germany
Hande Yaman	KU Leuven	Belgium

Organizing Committee

Víctor Blanco	Universidad de Granada	Spain
Marta Baldomero-Naranjo	Universidad de Cádiz	Spain
Carmen-Ana Domínguez-Bravo (Co-Chair)	Universidad de Cádiz	Spain
Inmaculada Espejo	Universidad de Cádiz	Spain
Elena Fernández	Universidad de Cádiz	Spain
Luisa I. Martínez-Merino (Co-Chair)	Universidad de Cádiz	Spain
Manuel Munoz-Márquez	Universidad de Cádiz	Spain
Juan M. Muñoz-Ocaña	Universidad de Cádiz	Spain
Raúl Páez	Universidad de Cádiz	Spain
Antonio M. Rodríguez-Chía	Universidad de Cádiz	Spain
Concepción Valero	Universidad de Cádiz	Spain
Nicolás Zerega	Universidad de Cádiz	Spain

Program

Wednesday, September 17, 2025

8:30–9:00	**Registration (H)**	
9:00–10:00	**Opening session (S)**	
10:00–11:00	**EWGLA Plenary talk (b)** Location and Transportation Problems in Humanitarian Logistics: Models, Insights, and Future Directions **Burcu Balçik** Ozyegin University, Turkey (Chair: Serena Fugaro)	
11:00–11:30	**Coffee (T)**	
11:30–12:30	**W1a: Discrete Location**	**W1b: Applications**
13:00–14:30	**Lunch (C)**	
14:30–15:50	**W2a: Capacitated Facility Location**	**W2b: Continuous Location**
16:00–16:30	**Coffee (T)**	
16:30–17:50	**W3a: Discrete Location**	**W3b: Network Design**
20:00–22:00	**Welcome reception (*)**	

Details of the Presentation Rooms

(a) Classroom Building (Aulario), 1st Floor, Room 1.20A
(b) Classroom Building (Aulario), 1st Floor, Room 1.20B
(S) Auditorium (Salón de Actos)
(H) Hall Office and Seminar Building (Edificio de Despachos y Seminarios)
(T) Cafeteria Terrace
(C) Cafeteria Dining Area
(*) Damajuana

Parallel Sessions Overview

11:30–12:50 W1a: Discrete Location (Chair: Alfredo Marín)

- Tackling the discrete α-neighbor p-center problem with integer programming.
  Elisabeth Gaar, *Markus Sinnl*.
- On integer programming models for the obnoxious p-median problem.
  Elisabeth Gaar, *Markus Sinnl*.
- An alternative Integer Programming formulation for the Linear Ordering Problem.
  Alfredo Marín, *Justo Puerto*.

11:30–12:30 W1b: Applications (Chair: Manuel Munoz-Marquez)

- Towards more sustainable Postal Supply Chains: a probabilistic approach to design Last-Mile Delivery Areas.
  Giuseppe Bruno, *Antonio Diglio*, *Carmela Piccolo*, *Eduardo Pipicelli*.
- Redesigning Italian health districts within new primary care regulatory frameworks.
  Giuseppe Bruno, *Antonio Diglio*, *Andreana Ferraioli*, *Carmela Piccolo*.
- The Strategic Berth Template Problem with Uncertain Arrival Times.
  Elena Fernández, *Manuel Munoz-Marquez*, *Francisco Saldanha-da-Gama*.

14:30–15:50 W2a: Capacitated Facility Location (Chair: Juan-José Salazar-González)

- Enforcing Stability in Capacitated Facility Location Problems with Ordinal Customer Preferences.
  Adam Dunajski, Sergio García, Akshay Gupte.
- Stable formulations for the Capacitated Facility Location Problem with Customer Preferences.
  Concepción Domínguez, Juan de Dios Jaime Alcántara.
- A capacitated facility location pricing problem with order.
  Herminia I. Calvete, Carmen Galé, Aitor Hernández, José A. Iranzo.
- Solution approaches for a fair multi-source capacitated facility location problem.
  Carlo Filippi, Gianfranco Guastaroba, Juan-José Salazar-González.

14:30–15:50 W2b: Continuous Location (Chair: Justo Puerto)

- Multiple Support Vector Machines based classifiers for multiclass classification.
  Víctor Blanco, Harshit Kothari, Jim Luedtke.
- A mathematical optimization approach for Multisphere Support Vector Data Description.
  Víctor Blanco, Inmaculada Espejo, Raúl Páez, Antonio M. Rodríguez-Chía.
- Conditional Facility Location Problems with Continuous Demand and a Rapid Transit Line.
  Thomas Byrne.
- On geodesic problems in location analysis: location with distance dependent regions.
  Justo Puerto.

16:30–17:50 W3a: Discrete Location (Chair: Eduardo Moreno)

- The Bounded Fixed-Charge Problem: A Compact and Tight Extended Formulation.
  Kobe Grobben, *Hande Yaman* , *Phablo Moura*.
- Location of services in urban areas using presence data and GIS information.
  Francesco Bianchi, *Giovanni Felici*, *Giuseppe Stecca*.
- Pattern-based Kernel Search for the Single-source Capacitated Facility Location Problem.
  Hannah Bakker, *Gianfranco Guastaroba*, *Stefan Nickel*, *M. Grazia Speranza*.
- Stochastic facility location problem with outsourcing costs.
  Eduardo Moreno, *Javiera Barrera*, *Ivana Ljubić*.

16:30–17:50 W3b: Network Design (Chair: Elena Fernández)

- Minmax location models for power system restoration problems.
  Hatice Çalık, *Dirk Van Hertem*, *Hande Yaman*.
- Dynamic Programming and Block-Cut Tree Decompositions for the Maximum Covering Network Design Problem.
  Felix Rauh, *Jannik Matuschke*, *Hande Yaman*.
- Extending the λ-Cent-Dian concept in Network Design Problems.
  Víctor Bucarey, *Natividad González-Blanco*, *Martine Labbé*, *Juan A. Mesa*.
- The Multiple-Picker Order Assignment Routing Problem.
  Elena Fernández, *Manuel Muñoz-Marquez*, *Jessica Rodríguez-Pereira*.

Thursday, September 18, 2025

9:00–10:00	**T1a: Location Routing**	**T1b: Network Design**
10:00–11:00	**EWGLA Plenary talk (b)** An EU-Wide Electricity Generation Capacity Expansion Problem subject to Network Constraints **Anthony Papavasiliou** National Technical University of Athens, Greece (Chair: Hatice Çalik)	
11:00–11:30	**Photo and coffee (T)**	
11:30–12:50	**T2a: Bilevel**	**T2b: Hub Location**
13:00–14:30	**Lunch (C)**	
14:30–15:50	**T3a: Covering Location**	**T3b: Capacitated Facility Location**
15:50–16:40	**Spanish Network Location Session (I)**	
18:00–21:00	**Social activities (*)**	

Details of the Presentation Rooms

(a) Classroom Building (Aulario), 1st Floor, Room 1.20A
(b) Classroom Building (Aulario), 1st Floor, Room 1.20B
(I) INDESS Auditorium (Salón de Actos)
(T) Cafeteria Terrace
(C) Cafeteria Dining Area
(*) City center

Parallel Sessions Overview

9:00–10:00 T1a: Location Routing (Chair: Maria Albareda-Sambola)

- Designing resilient networks: A robust approach to the location-routing problem.
  Bruna Figueiredo, Amaro de Sousa, Rui Borges Lopes.
- A Location-Routing Problem with Customers' Delivery Preferences.
  José Emmanuel Gómez-Rocha, José-Fernando Camacho-Vallejo, Elena Fernández.
- Resource balancing through route combination.
  Maria Albareda-Sambola, Juan A. Díaz, Dolores E. Luna-Reyes, Victoria Rebillas-Loredo.

9:00–10:00 T1b: Network Design (Chair: Antonio M. Rodríguez-Chía)

- Deep-learning Aided Crowdshipping Network Design with External Delivery Vehicles.
  Ramazan Çevik, Ali Şardağ, Barış Yıldız
- Scheduled Service Network Design for Integrated Passenger and Freight Transportation.
  Krissada Tundulyasaree, Emrah Demir, Rolf N. van Lieshout, Layla Martin, Tom Van Woensel.
- Cargo allocation problem on road transport subject to driving-time regulations.
  Inmaculada Espejo, Juan Manuel Muñoz-Ocaña, Teresa Navarro, Raúl Páez, Antonio M. Rodríguez-Chía.

11:30–12:50 T2a: Bilevel (Chair: Simona Mancini)

- Order then optimize: a flexible modeling framework in Location Science.
  Victor Blanco, Miguel A. Pozo, Justo Puerto, Alberto Torrejon.
- New generalized Stackelberg solutions in Security Games.
  Lina Mallozzi, Justo Puerto, Francisco Temprano.
- A Deterministic Utility Model for the Leader-Follower Competitive Facility Location Problem with Facility Attractiveness.
  Julius Hoffmann, Stefan Nickel.
- Competitive bi-level facility location with levels of service and stochastic customers preferences.
  Simona Mancini, Leandro C. Coelho.

11:30–12:50 T2b: Hub Location (Chair: Armin Lüer-Villagra)

- Locating Sorting Modules in a Multi-Hub E-Commerce Logistics Network.
  Zeynep Ezgi Kurban, Bahar Yetiş Kara, Oya Karaşan.
- Study of parameter perturbations in the uncapacitated p-hub median location problem with Machine Learning.
  Inigo Martin Melero, Mercedes Landete Ruiz, Vanesa Guerrero.
- Tight lower bounds for Multiple Allocation HLPs from two-index supermodular inequalities.
  Elena Fernández, Nicolás Zerega.
- A stochastic hub location and protection problem.
  Armin Lüer-Villagra, Gonzalo Méndez-Vogel, Vladimir Marianov.

14:30–15:50 T3a: Covering Location (Chair: Ioannis Giannikos)

- Enhancing Fairness in Emergency Medical Service: Single- and Bi-Objective Model Formulations.
  Isabel Wiemer, *Jutta Geldermann*.
- Maximal Covering Location Problem with Random Utilities for Urban Recycling: Modeling User Behavior and Bin Overflow Constraints.
  Gonzalo Méndez-Vogel, *Sebastián Dávila-Gálvez*, *Pedro Jara-Moroni*, *Jorge Zamorano*.
- Preliminary results on the generalized vertex cover problem.
  Juan Francisco Correcher, *Mercedes Landete*, *Juanjo Peiró*, *Hande Yaman*.
- Probabilistic Cooperative Coverage Location Problems: a Robust Optimization Approach.
  Ioannis Giannikos, *Maria Mihopoulou*.

14:30–15:50 T3b: Capacitated Facility Location (Chair: Pascual Fernández)

- A combinatorial branch-and-bound algorithm for the single-source capacitated facility location problem with strict customer preferences.
  Christina Büsing, *Felix Engelhardt*, *Sophia Wrede*.
- Combined risk attitudes in optimization models.
  Juan M. Muñoz-Ocaña, *Antonio M. Rodríguez- Chía*, *Francisco Saldanha-da-Gama*.
- Optimal location of synchronization servers and robust radio base concentrator assignation in telecommunications networks.
  Pedro Piñeyro, *Antonio Mauttone*, *Federico Molina*, *Enrique Munné*, *Alejandro Pascual*, *Carlos Testuri*.
- A Capacitated Discrete Competitive Facility Location and Design Model with Two Customers Choice Rules Sequentially Applied.
  Pascual Fernández, *Algirdas Lančinskas*, *Julius Žilinskas*.

Friday, September 19, 2025

9:20–10:00	**F1a: Location Routing**	**F1b: Humanitarian Logistics**
10:00–11:00	**IWOLOCA Plenary talk (b)** Celebrating Thirty EWGLA Meetings: A personal retrospective on Location Analysis **Vladimir Marianov** Pontificia Universidad Católica de Chile, Chile (Chair: Víctor Blanco)	
11:00–11:30	**Coffee (T)**	
11:30–12:50	**F2a: Covering Location**	**F2b: Graph Theory**
13:00–14:30	**Lunch (C)**	
14:30–15:30	**F3a: Bilevel**	**F3b: Applications**
15:30–16:00	**Coffee (T)**	
16:00–17:00	**F4a: Competitive Location**	**F4b: Humanitarian Logistics**
17:00–17:50	**EWGLA Session (S)**	
20:30–22:30	**Gala dinner (*)**	

Details of the Presentation Rooms

(a) Classroom Building (Aulario), 1st Floor, Room 1.20A
(b) Classroom Building (Aulario), 1st Floor, Room 1.20B
(S) Auditorium (Salón de Actos)
(T) Cafeteria Terrace
(C) Cafeteria Dining Area
(*) González Byass

Parallel Sessions Overview

9:20–10:00 F1a: Location Routing (Chair: Lavinia Amorosi)

- A Time Space Network Model for a Truck and Drones Delivery System with Battery Recharging and Variable Speeds.
  Lavinia Amorosi, Paolo Dell'Olmo, Justo Puerto, Carlos Valverde.
- Preemptive Drone Coverage Path Planning with Variable Altitudes.
  Lavinia Amorosi, Paolo Dell'Olmo, Justo Puerto, Carlos Valverde.

9:20–10:00 F1b: Humanitarian Logistics (Chair: Jessica Rodríguez-Pereira)

- Team Formation and Debris Assignment for Post-Disaster Search and Rescue Operations: An Operational Research Perspective.
  Egehan Uğraş, Zehranaz Dönmez Varol, Bahar Y. Kara.
- Logistics planning for post-disaster resilience assessment under uncertainty.
  Asena Kaplan, Jessica Rodríguez-Pereira, Burcu Balçik, Marie-Ève Rancourt, Gilbert Laporte.

11:30–12:50 F2a: Covering Location (Chair: Claudio Sterle)

- The Maximum Capture Facility Location with Random OWA Utilities.
  Concepción Domínguez, Ricardo Gázquez, Juan Miguel Morales, Salvador Pineda.
- Upgrading on edges and facilities for the Multi-Type Maximal Covering Location Problem.
  Marta Baldomero-Naranjo, Ricardo Gázquez, Antonio M. Rodríguez-Chía.
- Integrating E-Scooters into Urban Mobility: Coupled Location Problems for Seamless Multimodal Transport.
  Nicolas Fröhlich, Klara Hoffmann, Anita Schöbel.
- The Clustered Multimode Set Covering Problem.
  Andrea Mancuso, Antonio Manuel Rodríguez-Chía, Francisco Saldanha-da-Gama, Claudio Sterle.

11:30–12:50 F2b: Graph Theory (Chair: Mercedes Landete)

- New mixed-integer linear models for the 2-Layer Straight Line Crossing Minimization Problem.
  Inmaculada Espejo, Mercedes Landete, Juanjo Peiró.
- Uniform partitioning problems and k-dimensional assignment.
  Isabella Lari, Federica Ricca, Andrea Scozzari.
- Optimal Mediated Graphs and Where to Find Them: Hidden Combinatorics Underneath Conic Algebraic Geometry.
  Víctor Blanco, Miguel Martínez-Antón.
- Linear constraints for describing spanning trees representing complete linkage dendrograms.
  Martine Labbé, Mercedes Landete, Marina Leal, Lorena Nácher.

14:30–15:30 F3a: Bilevel (Chair: José-Fernando Camacho-Vallejo)

- A bilevel model for locating garment recycling bins.
  Dámaris Arizhay Dávila Soria, Mario Alberto Aguirre-López, Jose-Fernando Camacho-Vallejo.
- Optimizing the Location of Waste Transfer Stations and Treatment Facilities for Sustainable Urban Solid Waste Management.
  Krystel M. Rodríguez, José-Fernando Camacho-Vallejo, Rosa G. González-Ramírez, Juan G. Villegas.
- A Bilevel Approach to the Location-Routing Problem for PET Bottle Collection.
  José-Fernando Camacho-Vallejo, Eva Selene Hernández-Gress, Carlos Corpus , Ali Zahedi.

14:30–15:30 F3b: Applications (Chair: Anita Schöbel)

- A Multi-Objective Mixed Integer Linear Programming Model for In-Motion Charging Location Planning.
  Mohammad Javad Eslami, Thomas Byrne, Mahdi Doostmohammadi.
- New Mathematical Models of Clustered Vehicle Routing Problem for the Waste Collection Process.
  Yaren Çelik, Kumru Didem Atalay, Berna Dengiz, Tusan Derya, Bahar Yetiş Kara.
- The Skip-Stop Problem in Public Transportation.
  Ricardo Reicherz, Anita Schöbel.

16:00–17:00 F4a: Competitive Location (Chair: Pedro Godinho)

- A Stackelberg location game on the plane with equilibrium delivered prices.
  José Fernández, *Boglárka G. Tóth*.
- Collection points placement in urban delivery: A game-theoretic analysis of public and competitive strategies.
  Fabio Mercurio, *Margarida Carvalho, Sonja U.K. Rohmer, Loe Schlicher, Tom Van Woensel*.
- Competitive Location with NPV Maximization in a Discrete Setting: Comparing Sequential and Simultaneous Decisions.
  Pedro Godinho.

16:00–16:40 F4b: Humanitarian Logistics (Chair: Serena Fugaro)

- Managing Involuntary Migration.
  Melek Tuncel, *Bahar Y. Kara*.
- Bi-objective Location of Temporary Logistics Hubs for Enhancing Post-Disaster Relief Operations.
  Serena Fugaro, *Antonino Sgalambro*.

Invited Speakers

Location and Transportation Problems in Humanitarian Logistics: Models, Insights, and Future Directions

Burcu Balçık
Özyeğin University, Türkiye, burcu.balcik@ozyegin.edu.tr

Keywords: Humanitarian logistics, Operations Research

Introduction

Humanitarian logistics involves the planning, implementing, and coordinating supply chain and logistics activities to ensure the timely and effective delivery of assistance to populations affected by crises. It is a young research field that has expanded rapidly over the past two decades in response to the increasing frequency and severity of natural disasters, conflicts, public health emergencies, and growing vulnerabilities across various regions. The complexity and scale of today's humanitarian operations make the need for systematic, data-driven, effective, equitable, and efficient solutions more urgent than ever. In this regard, Operations Research (OR) has the potential to play a critical role in supporting decision-making in humanitarian logistics.

Existing humanitarian logistics literature addresses numerous problems involving location and transportation decisions, often under severe uncertainty, time pressure, and information scarcity. Unlike in many commercial settings where optimization focuses on efficiency or profit, humanitarian contexts require models that also incorporate equity, urgency, and ethical considerations. Understanding operational realities is key to designing OR approaches that can truly make an impact.

This plenary talk provides an overview of OR problems involving location and transportation decisions across the disaster management cycle and illustrates how such models can support better disaster preparedness and response. Selected research projects will be presented to highlight the practical challenges faced in various phases. The talk will also reflect on the role of practitioner collaboration and outline future research directions.

OR Problems across Disaster Management Phases

Each phase of the disaster management cycle, which includes mitigation, preparedness, response, and recovery, involves distinct logistical problems, shaped by unique operational priorities and constraints.

Before a disaster, in the mitigation phase, the focus is on building resilience and reducing long-term vulnerabilities. Typical problems include strengthening critical infrastructure, designing disaster-resilient transportation networks, and developing early warning systems that trigger action before disasters hit. The preparedness phase emphasizes the development of logistical capacity and mechanisms for effective emergency response. Relevant problems include strategically prepositioning relief supplies, designing supply chains and distribution networks, and planning inventories of essential goods. Addressing uncertainty in demand, access conditions, and funding is a significant challenge at this stage.

In the aftermath of a disaster, the response phase is characterized by urgency and information scarcity. Organizations must rapidly assess needs and deliver aid in disrupted environments. Key problems include assessing needs and damage, prioritizing affected regions, and distributing aid under dynamic conditions. The recovery phase focuses on restoring infrastructure and providing continued support to affected populations. Relevant logistics problems include coordinating debris removal, delivering long-term aid, and rebuilding interdependent systems such as transportation, power, and healthcare networks.

Each phase poses specific modeling challenges, but there is a unifying theme: the need for evidence-based decision-making under uncertainty. Drawing on long-term collaborations with humanitarian organizations, I will share insights into how real-world operational needs have shaped problem formulations, modeling approaches, and the design of practical decision-support tools that leverage the power of operations research (OR) to address the complexities of data-scarce, resource-constrained, and high-stakes humanitarian environments.

Future Directions

There are numerous opportunities for the OR and location science communities to contribute meaningfully to humanitarian logistics and disaster management. Future research could focus on themes such as adaptive planning, anticipatory action, collaborative and coordination mechanisms, as well as the opportunities and challenges introduced by emerging technologies. Advancing work in these areas requires deeper collaboration with practitioners and stronger interdisciplinary engagement. This presentation will conclude with a discussion of promising directions that can help design better humanitarian logistics systems using OR and analytics.

An EU-Wide Electricity Generation Capacity Expansion Problem subject to Network Constraints

Daniel Avila [a], **Anthony Papavasiliou** [b,*], **Marilena Zampara** [b], **Georg Thomassen** [c], **David Pozo-Camara** [d]

[a] Arktos Analytics, Belgium, daniel_avila@mail.ntua.gr
[b] National Technical University of Athens, Greece,
papavasiliou@mail.ntua.gr, zampara@power.ece.ntua.gr
[c] Joint Research Center (Ispra), Italy, Georg.THOMASSEN@ec.europa.eu
[d] Joint Research Center (Petten), Netherlands, David.POZO-CAMARA@ec.europa.eu
[*] Plenary speaker.

Keywords: Decomposition algorithms, high performance computing

Introduction

The European Union has set ambitious renewable energy integration targets over the following decades as part of its climate, environmental protection and sustainability policy. These targets translate into concrete minimum targets for the supply of renewable energy sources, in particular wind and solar energy. Our focus in this work is to formulate and solve an EU-wide power generation expansion problem with such renewable energy targets. The model that we formulate provides an optimal generation expansion plan while accounting for uncertainty in future European climate scenarios as well as constraints in the ability of the power network to transport electric power from locations of abundant renewable supply to locations of high electricity demand.

Problem Description

The generation capacity expansion problem that we formulate is a massive-scale two-stage stochastic linear program. The first-stage decisions of the model correspond to hundreds of renewable energy projects that are to be selected among thousands of candidates. Uncertainty corresponds to the realization of climate scenarios, which correspond to past climate years and translate to different patterns of locational demand for electric power. The second-stage decisions correspond to the locational production of electric energy, and the resulting routing of this electric energy over the electric power grid, as dictated by physical laws which result in the so-called power flow equations.

Algorithmics

The resulting capacity expansion problem is of massive scale. As it covers the entire European continent, the underlying network consists of thousands of high-voltage power grid nodes, thousands of high-voltage transmission lines, a one-year horizon with high granular resolution (i.e. close to an hourly resolution), and 15 climate scenarios. Moreover, the annual renewable energy integration targets create an interesting additional complication: the weighted average of renewable energy that is absorbed over different scenarios must exceed a minimum threshold.

This translates into a direct coupling of scenarios, in contrast to an indirect coupling via first-stage decisions, which implies that standard decomposition techniques (such as cutting plane methods) cannot be applied directly.
We propose a two-layer decomposition algorithm for tackling the problem. The outer layer is a reformulation, inspired by recent literature on capacity expansion [2], which allows us to decouple the constraint that binds the uncertainty scenarios. A decomposition strategy for decoupling scenarios follows, which relies on standard regularization methods [1]. An inner decomposition strategy is employed for decoupling the time stages of each scenario, which is inspired by recent literature on capacity expansion [2]. The overall algorithm is implemented on the ARIS high performance computing cluster of GRNET. An initialization strategy which computes anticipative capacity configurations for each region of the EU is employed for initializing the algorithm from a reasonable starting point. This allows us to tackle the problem within a few days of run time using a few hundred CPUs for implementing our proposed decomposition.

Results

We analyze the results of our algorithm by computing the value of the stochastic solution, as well as the expected value of perfect information. We further compare the results of this EU-wide solution to less coordinated strategies that tackle isolated European regions in isolation.

Bibliography

[1] Birge, John R., and Francois Louveaux. Introduction to stochastic programming. *Springer Science and Business Media*, 2025.

[2] Pecci, Filippo and Jenkins, Jesse D. Regularized benders decomposition for high performance capacity expansion models. *IEEE Transactions on Power Systems*, 2025.

Celebrating Thirty EWGLA Meetings: A personal retrospective on Location Analysis

Vladimir Marianov [a,b]

[a] Departamento de Ingeniería Eléctrica, Pontificia Universidad Católica de Chile, marianov@uc.cl
[b] Instituto Sistemas Complejos de Ingeniería (ISCI), vladimir.marianov@gmail.com

Keywords: Emergency services, Congested facilities, Hub location, Competitive location

By 1985, when the first EWGLA Meeting was held in Dijon, France (featuring 12 talks), there was already an active community working in the field of Facility Location. Researchers were proposing sophisticated models, studying mathematical properties of the problems, finding applications, and developing solution methods. To follow all the literature on Location Analysis was already a very difficult task. Now, it became nearly impossible, so this talk will be limited to a some of the areas I have touched since the '80s.

A hot topic in the '80s was the location of emergency services, on which there was already much done by ReVelle, Church, Daskin, Larson, Berman, Odoni, Batta, Chiu, Brandeau, et al. These researchers belonged to two disjoint groups, and between them there were very few mutual citations. There was a gap consisting of integrating queueing and linear integer models. I made this my first task, and Emergency Services will be the first area of the talk.

With Dan Serra we found in 1993 a problem which, unlike mobile emergency services, was untouched in the literature: Representation of congested immobile facilities, especially using linear formulations. This gave birth to a second line of research with unexpected ramifications, and this will be the second area in the talk.

At the same time, with Serra and ReVelle, we got interested in two problems: the hierarchical maximum capture problem, and the first competitive hub location problem. There were two lines involved: Hub location problems, and competitive location problems. I followed both.

Hub location problems were suggested by Goldman in 1969, put in the form of an integer programming formulation by O'Kelly in 1986 and 1987, and being dealt with by O'Kelly, Campbell, Aykin, Klincewicz, the Skorin-Kapovs, Ernst and Krishnamoorthy, Drezner, Sasaki and Suzuki, among others. There were still untouched extensions, which are described in the talk.

Last, competitive problems had a long story: Hotelling in 1929 solved (with a flaw) the problem of two firms on a bounded line. This was a field with several big names working on it, including the Drezners, Berman, Eiselt, Pelegrin, Plastria, Fernández, among others. I got into the field, starting with simple competition rules and ending with more elaborated models of consumer behavior.

As someone said, “it is very difficult to predict — especially the future.” And predictions become a joke when the future arrives. Still, I will risk mentioning two or three topics that look promising.

Abstracts

Resource balancing through route combination

Maria Albareda-Sambola [a,*], Juan A. Díaz [b], Dolores E. Luna-Reyes [b], Victoria Rebillas-Loredo

[a] Universitat Politècnica de Catalunya, maria.albareda@upc.edu
[b] Universidad de las Américas, Puebla, juana.diaz@udlap.mx, dolorese.luna@udlap.mx
[*] Presenting author.

Keywords: Vechicle Routing, Route synchronization

Introduction

This work addresses the Multi-Depot Vehicle Routing Problem (MDVRP) with Vehicle Interchanges. In the MDVRP, one aims at minimizing the cost of distributing the goods demanded by the customers in a region by vehicle routes, under the assumption that the capacities of the containers must be satisfied, limits on the route durations are respected, and each route finishes at the same depot where it started.
When the demands of the customers are not evenly spread in the region, the constraints concerning vehicle capacities and those concerning route durations may enter in conflict, and, as a result, some routes may be obtained where either the capacity of the vehicle containers or the driver time availability are significantly underused.
The MDVRP with vehicle interchanges (MDVRP-VI) is is an extension of this problem that aims at avoiding this. To this end, couples of routes can meet at prespecified locations in order to interchange their containers. Therefore, although each truck/driver pair must finish its route at its original location, containers can perform trips from one depot to a different one. This allows for more flexibility and lower transportation costs are expected.

Methodology

We present a three-phase matheuristic for addressing the MDVRP-VI. In a first phase, a GRASP heuristic is presented, to build a diversity of good quality paths starting at a depot, and visiting some customers. In a second phase, some of the paths built in the GRASP phase are combined using mathematical programming to generate a feasible solution. In a third phase, this solution is improved by means of a Local Search based algorithm.
At each iteration of the GRASP component of the heuristic, a partial route is either finished, with a probability that takes into account route duration and vehicle capacity, or it is extended with a new customer following a randomized nearest-neighbor criterion. The algorithm terminates when all customers have been added in one of the paths.
Then, in the second phase of the proposed method, all different paths obtained on a series of runs of the GRASP phase are considered, and they are combined into one feasible solution using mathematical programming.
Finally, the solution obtained is improved by applying Local Search over a variety of neighborhoods.

Preemptive Drone Coverage Path Planning with Variable Altitudes

Lavinia Amorosi [a,*], Paolo Dell'Olmo [a], Justo Puerto [b], Carlos Valverde [b]

[a] Department of Statistical Sciences, Sapienza University of Rome, Italy,
lavinia.amorosi@uniroma1.it, paolo.dellolmo@uniroma1.it,
[b] Department of Statistical Sciences and Operational Research, University of Seville, Spain,
puerto@us.es, cvalverde@us.es
[*] Presenting author.

Keywords: Monitoring system, Second Order Cone Programming, UAVs

Introduction

We present a second order cone mixed-integer programming formulation for a monitoring system based on one drone that moves freely in the space. We assume to have a set of not overlapping areas in the plane to be covered, represented by polygons, and one depot. The problem consists in finding the set of tours starting and ending at the depot the drone must perform in order to cover all the areas under analysis, taking into account its limited endurance. The proposed formulation embeds the drone altitude selection from a set of possible values associated with each area. This is motivated by the necessity to inspect each area with different levels of precision. Moreover, it is assumed that there is a set of points, with limited cardinality, associated with each area, from where the drone can interrupt the monitoring and exit to reach another area where the same process can be repeated. When the drone attains its minimum energy level, it must go back to the depot to swap battery and start a new tour, until all the areas have been covered. The optimization is performed by minimizing the total completion time. Preliminary computational results on a testbed of artificial instances are presented together an analysis of the obtained solutions.

Pattern-based Kernel Search for the Single-source Capacitated Facility Location Problem

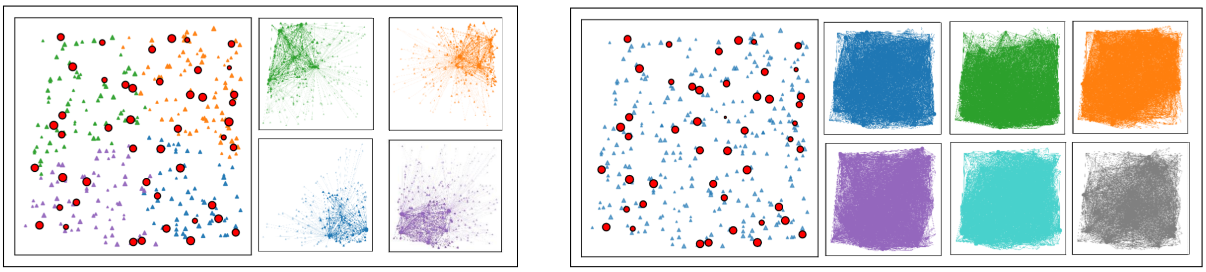
Hannah Bakker [a,*], Gianfranco Guastaroba [b], Stefan Nickel [a], M. Grazia Speranza [b]

[a] Karlsruhe Institute of Technology, Germany hannah.bakker@kit.edu, stefan.nickel@kit.edu,
[b] University of Brescia, Italy gianfranco.guastaroba@unibs.it, grazia.speranza@unibs.it
[*] Presenting author.

Keywords: Single-source CFLP, Kernel Search

Pattern-based Kernel Search

We introduce Pattern-based Kernel Search (PaKS), a two-phase heuristic expanding the successful Kernel Search (KS) for the capacitated facility location problem with single sourcing (SS-CFLP) presented in [3]. KS is a metaheuristic that leverages the fact that solving a sequence of small-size BIPs can be more efficient than solving one large BIP. KS partitions decision variables into disjoint subsets: a kernel containing the "promising variables" (those likely to be non-zero in an optimal solution) and complementary buckets. An initial solution is obtained by solving the restricted BIP that includes only the kernel variables while forcing all others to zero. Subsequently, a sequence of restricted BIPs combining kernel and bucket variables is solved, progressively improving the solution and updating the kernel with the non-zero variables.



(a) PaKS.

(b) KS [3].

Figure 1: Illustration of the kernel locations (red circles) among facilities (circles) and customers (triangles) in the large square, the color-coded assignment of facilities and customers to distinct regions, and the resulting buckets for PaKS and KS (smaller squares). The illustration of the buckets displays how the implied spatial information is provided by PaKS through bucket allocations to distinct regions.

The performance of KS is critically impacted by the partitioning of the variables between the kernel and the buckets. KS relies solely on information from the LP relaxation to make this decision. In contrast, PaKS bases the partitioning on the results of an analysis of the instance conducted in its first phase. PaKS solves the initial LP relaxation plus a series of modified LP relaxations. Pattern recognition is then applied to these solutions to determine the importance and interrelationships among decision variables. As a result, facilities and customers are divided into distinct regions, with each region corresponding to a bucket. As illustrated in Figure 1 (a), in PaKS the variables in each bucket are regionally confined, ensuring that only allocations to proximate customers are considered. Consequently, PaKS solves a sequence of restricted MIPs refining the initial kernel solution region by region to capture the relevant interactions in the restricted BIPs. A beneficial outcome is that the spatial information obtained from the first phase significantly reduces the set of allocation variables, leading to smaller restricted BIPs and enabling the efficient solution of larger problem sizes. The second phase of PaKS works along the general lines of a kernel search framework.

Computational Results

We conducted extensive computational experiments on sets of well-known benchmark instances. PaKS was implemented in Python 3.9 and each BIP was solved with CPLEX version 22.1. For the SS-CFLP, the largest instances solved in the literature are the TBED-1 set introduced in [1], which comprises up to 1000 facilities and customers each. After comparing a novel implementation of KS with state-of-the-art heuristics, and CPLEX, our results show that KS remains the best-performing heuristic from the literature in terms of both objective function value and solution time.

Both KS and PaKS outperform CPLEX and perform comparably on TBED-1. However, a detailed analysis reveals that PaKS outperforms KS on the largest instances in the set. We further extended our experiments to larger instances in sets TB-A, TB-B, and TB-C ([2]), which include up to 2000 facilities and customers each, and have, until now, been solved only for the multi-source CFLP. As shown in Figure 2 for TB-A, PaKS achieves significantly lower objective function values than both KS and CPLEX. Furthermore, it identifies feasible solutions more robustly than KS within the given timelimit–99% of the large-scale instances compared to 79% for KS. These findings clearly demonstrate PaKS's strong potential for addressing very large-scale problems.

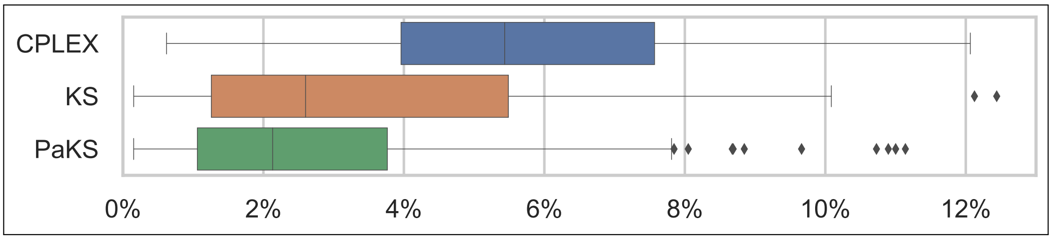


Figure 2: Distribution of the average percentage gap between the objective value and the best known lower bound for 140 TB-A instances, each solved within a 7200-second time limit.

Bibliography

[1] Avella, P., and Boccia, M. A cutting plane algorithm for the capacitated facility location problem. *Computational Optimization and Applications*, 43(1), 39–65, 2007.

[2] Avella, P., Boccia, M., Sforza, A., and Vasil'ev, I. An effective heuristic for large-scale capacitated facility location problems. *Journal of Heuristics*, 15(6), 597–615, 2008.

[3] Guastaroba, G., and Speranza, M.G. A heuristic for BILP problems: The Single Source Capacitated Facility Location Problem. *European Journal of Operational Research*, 238(2), 438–450, 2014.

Multiple Support Vector Machines based classifiers for multiclass classification

Víctor Blanco [a,*], Harshit Kothari [b], Jim Luedtke [b]

[a] Universidad de Granada, vblanco@ugr.es
[b] University of Wisconsin-Madison, jim.luedtke@wisc.edu, hkothari2@wisc.edu
[*] Presenting author.

Keywords: Supervised Classification, Multi-hyperplanes Location, Mixed Integer Second Order Cone Optimization, Clustering.

Introduction

Support Vector Machines (SVM) is one of the most popular optimization based tools for supervised binary classification [2]. The linear SVM methodology is based on finding the location of a separating hyperplane between the two classes that both maximizes the separation between classes and minimizes the sum of the misclassification errors. One of the main advantages of this tool is that, using the convexity properties of the problem one can compute, via the *kernel trick*, non linear separators with the same (or less) effort than a linear one. Nevertheless, this tool is designed only for two-class instances by means of locating single separating hyperplane. Some effort have been done in the last years to extend SVMs to multi-class instances by using multiple separating hyperplanes, but the challenge is still open due to the computational difficulty of the problem that is compared with the extension in Facility Location from the continuous single facility location problem (a.k.a. Weber problem) to its multi-facility counterpart.

The most popular extensions of SVM to instances with multiple classes, although suboptimal, are the so-called One-Versus-Rest and One-Versus-One, which are based on solving, independently, small instances of binary SVMs for different subsets of the training sample. Although one can extend the properties of SVM to these approaches, it has been shown that they allow to provide good classifiers only for instances which are geometrically simple. In other line of extensions, in [3], [4], and [5] the authors propose different compact mathematical optimization based approaches to model the multiclass SVM problem. Nevertheless, these extensions are based on mathematical optimization models which do not keep the main paradigm of the optimization problem behind SVM, which is to construct linear structures that both minimize the missclassification errors but also that maximize the separation between the different classes. With this in mind, in [1], the authors propose a compact Mixed Integer NonLinear programming model to maximize the minimum separation between the classes assigned to the cells induced by the arrangement of hyperplanes. The main bottleneck of this approach is the limited size of the training instances that can be optimally solved, since the models consider different discrete decisions in the models as the assignments of cells to classes, assignments of observations to cells and classes, different types of missclassification

errors, etc.
In this work, we provide an alternative and simplified compact mathematical optimization model for the multiple-hyperplanes SVM methodology with significantly fewer variables and constraints than the previous approaches, also with fewer parameters to tune. We strengthen the proposed model by reducing the number of variables and handling symmetries with different strategies. We also prove that the kernel trick can be applied to our methodology, being able to construct multiple non linear separating classifiers. For larger instances, we provide a clustering based adaptative math-heuristic approach that allows to derive good quality classifiers for large scale instances, as well as an add-hoc parameter tuning strategy that avoid searching on a huge grid of possible parameters. First, we validate our proposal computationally, comparing the performance of the mathematical optimization model of our model with all its different strenthening strategies, and also with other models in the literature. Second we analyze the performance of our approach both on synthetic and real datasets.

Acknowledgements

This research has been partially supported by grant PID2020-114594GB-C21 funded by MICIU/AEI/ 10.13039/501100011033, grant RED2022-134149-T funded by MICIU/AEI /10.13039/501100011033, and the IMAG-María de Maeztu grant CEX2020-001105-M/AEI/10.13039/501100011033.

Bibliography

[1] Blanco, V., Japón, A., and Puerto, J. Optimal arrangements of hyperplanes for svm-based multiclass classification. *Advances in Data Analysis and Classification*, 14(1):175–199, 2020.

[2] Cortes, C. and Vapnik, V. Support-vector networks. *Machine learning*, 20(3):273–297, 1995.

[3] Crammer, K. and Singer, Y. On the algorithmic implementation of multiclass kernel-based vector machines. *Journal of machine learning research*, 2(Dec):265–292, 2001.

[4] Lee, Y., Lin, Y., and Wahba, G. Multicategory support vector machines: Theory and application to the classification of microarray data and satellite radiance data. *Journal of the American Statistical Association*, 99(465):67–81, 2004.

[5] Weston, J. and Watkins, C. Support vector machines for multi-class pattern recognition. In *Esann*, volume 99, pages 219–224, 1999.

Conditional Facility Location Problems with Continuous Demand and a Rapid Transit Line

Thomas Byrne *

University of Strathclyde, tom.byrne@strath.ac.uk
* Presenting author.

Keywords: Continuous location, planar facility location, computational geometry, spatial demand, Voronoi diagrams, Manhattan distance, rapid transit line

Travel time is a critical issue, with the average cost of a unit of time increasing and so with it the customers' and suppliers' willingness to pay more in order to save time (one of the rarest resources they possess). The prominent question when given a surplus of choice of comparable suppliers is: which supplier can the customer reach the fastest? Crucial to the answer to this question is location, dictating the routes taken from supply to demand and so the speed of access.

The vast majority of planar location problems rely on the assumption that the traversable region is navigable at a uniform speed. However, this supposition is not a realistic one for many real-world applications. Differing infrastructure allows journeys to be conducted on routes of variable set speeds (e.g. driving along a country road or an autobahn) and using different modes of transfer (e.g. by foot or by bullet train). Due to the transport provisions available, the optimal path taken between two points is rarely a straight line, and usually some diversion is made in order to be able to travel along a faster route. Therefore we can rarely use 'straight-line' distances to model how people and things move between points, and must instead revert to geodesic distances.

Additionally, while a discrete set of demand points often adequately reflects industrial problems, for commercial and public service facilities in an urban environment, there can be millions of potential customers, and it is impracticable to represent every customer site as a separate demand point. Instead, one could aggregate customers into a smaller number of meta-customers, e.g. by postal codes, census tracts, or wards. This, however, introduces various kinds of aggregation errors to the problem, which can be quite pronounced. A second, more accurate, approach is to model customer demand as continuously distributed over the specified area which also lends itself much better to the uncertain and sporadic nature of some demands.

Solving either of these two extensions (continuous demand and a rapid transit line) independently is challenging, but both combined is even more so. Planar location problems with discrete demand and Euclidean distances can be solved analytically, without having to investigate any geometric properties of the problem. For the Manhattan norm, one can even discretise the solution space and pose the problem as an equivalent discrete location problem [3]. Not so for continuous demand distributions with multiple facilities. Following stipulation of the locations of all p facilities, the demand space has to be subdivided into areas known as 'Voronoi cells' which represent each facility's captured demand; the resulting partition is

called the ‘Voronoi diagram’. In order to solve the problem, merely calculating the Voronoi diagram based on the facility locations is insufficient. Instead, it is essential to study the *structure* of the Voronoi diagram, i.e. the position and the geometry of the cell boundaries, and how it changes dynamically when one or more of the facilities ‘move around’ on the plane. Unfortunately, this structure can alter dramatically, which makes it generally nigh impossible to represent the objective function of the problem in closed form, and renders the formulation of the underlying optimisation problems very challenging [1].
These difficulties are exacerbated when we introduce rapid transit lines. In this case, we have to replace the regular ‘straight-line’ distances with their geodesic counterparts. While some solution methods for line location problems with discrete demand require the calculation of the line-enhanced Voronoi diagram, this static Voronoi diagram of the fixed demand points is not affected by the locations of the facilities and there is not even a derivable equivalent for continuous customer demand, invalidating any exact solution method for discrete demand line problems.

This work mirrors closely that of [2] and explores a variety of conditional location problems (wherein the optimal location for an additional facility is sought) over a convex polygonal market region in the rectilinear plane. We assume that the demand is continuous and uniform within the market region, with customers being served by the nearest facility only (measured in time). Additionally, contained within the market region is one known rapid transit line (along which paths can travel at a preset constant speed) and we consider separately the properties that the rapid transit line can be accessed only at its endpoints or at any point along its route. Our goal is to develop a polynomial exact algorithm to work with this continuous demand and an arbitrary rapid transit line. To that end, we begin with an in-depth analysis of shortest paths in the presence of a rapid transit line and the representation of the bisectors of two facilities affected by the rapid transit line as well as the conditions for its existence within the Voronoi diagram. Following this, a detailed investigation into the structural properties of geodesic Voronoi diagrams enables us to solve the overlying optimisation problem itself by restricting the location of the new facility to a sub-region where the resulting geodesic Voronoi diagram is ‘structurally identical’ for every point in the region. Given such regions, we derive a parametric representation of the objective function which is valid for any location in the region. By this means we optimise the location of the new facility over this region using classical non-linear programming techniques, and the best optimal location of each sub-region is the optimal solution to the problem.

Bibliography

[1] Averbakh, I., Berman, O., Kalcsics, J., and Krass, D. Structural properties of Voronoi diagrams in facility location problems with continuous demand. *Operations Research* 62(2):394–411, 2015.

[2] Byrne, T. and Kalcsics, J. Conditional facility location problems with continuous demand and a polygonal barrier. *European Journal of Operational Research* 296(1):22–43, 2022.

[3] Francis, R.L. and White, J.A. *Facility layout and locations: An analytic approach*. Prentice Hall, Englewood Cliffs, N.J., 1974.

Minmax location models for power system restoration problems

Hatice Çalık [a,b,c,*], Dirk Van Hertem [a,b,c], Hande Yaman [d]

[a] KU Leuven, Department of Electrical Engineering, ELECTA, Leuven, Belgium
[b] EnergyVille, Genk, Belgium
[c] Energy Transmission Competence Hub, EnergyVille, Genk, Belgium
[d] KU Leuven, Faculty of Economics and Business, ORSTAT, Leuven, Belgium
[*] Presenting author, hatice.calik@kuleuven.be.

Keywords: Minmax Location, Discrete Optimization, Network Design, Set Partitioning, Energy

Introduction

In recent decades, we have experienced numerous extreme weather events due to climate change. Many of these events resulted in disruptions to power systems, leading to outages or complete blackouts. Blackouts are emergency situations that require efficient and effective management, as prolonged blackouts can have profound economic and societal impacts [3]. Europe has ambitious goals to reach net zero greenhouse gas emissions by 2050. Achieving this requires transitioning to power systems that utilize renewable energy sources and battery energy storage systems (BESS). This paced transition necessitates effective decision-making for the careful selection of BESS locations, combined with efficient restoration of power systems after potential blackouts.

In a complete blackout situation, all network components are down, and there is no electricity generation, transmission, or distribution. In such scenarios, the power system is restored gradually by first energizing the so-called *black-start generators* (BSs), which are capable of restarting themselves. Next, the order of energizing the non-black-start generators (NBSs) and critical loads, such as hospitals and traffic lights, must be determined. These NBSs and critical loads require a certain amount of external power (cranking power) to be started. NBSs have varying cranking powers and periods (time needed to begin generating power), generation capacities, and ramping periods to reach maximum capacity. The problem, where the objective is to minimize the latest start-up time of all components, is referred to as the *generator start-up sequencing problem* (GSS). GSS is NP-Hard [4].

During power system restoration, it is crucial to prevent network overload and ensure stability to avoid cascading power outages. To facilitate this, a common practice is to divide the network into islands, where each island has a BS and all network components within an island are connected [6]. The integration of islanding and GSS, combined with BESS location decisions, results in a highly challenging NP-Hard optimization problem.

Inspired by the effective p-center formulations in the location literature [5, 1], we develop integer programming formulations and decomposition algorithms for solving the aforementioned power system restoration problems. We improve the GSS formulation by [2] to reduce the number of variables and constraints which we then solve very efficiently within a binary search framework. This inspires us in solving the integrated islanding and GSS problem more efficiently compared to the formulation by [4]. We finally exploit these methods to solve the generalized problem with location decisions.

Bibliography

[1] Calik, H. and Tansel, B. C. Double bound method for solving the p-center location problem. *Computers & Operations research*, 40 (12), 2991–2999, 2013.

[2] Çalık, H., Ergun, H., Yurtseven, K., and Van Hertem, D. A bi-objective approach to power system restoration with renewable participation. IEEE 2024 18th International Conference on Probabilistic Methods Applied to Power Systems (PMAPS 2024), Date: 24-26 Jun 2024, Location: Auckland University of Technology, Auckland, New Zealand, 2024.

[3] Capitanescu, F. Are We Prepared Against Blackouts During the Energy Transition?: Probabilistic Risk-Based Decision Making Encompassing Jointly Security and Resilience. *IEEE Power and Energy Magazine*, 21 (3), 77–86, 2023.

[4] Chopra, S., Qiu, F., and Shim, S. Parallel Power System Restoration. *INFORMS Journal on Computing*, 35 (1), 233–247, 2023.

[5] Elloumi, S., Labbé, M., and Pochet, Y. A new formulation and resolution method for the p-center problem, *INFORMS Journal on Computing*, 16 (1), 84–94, 2004.

[6] Qiu, F. and Li, P. An integrated approach for power system restoration planning. Proceedings of the IEEE, 105 (7), 1234–1252, 2017.

A Bilevel Approach to the Location-Routing Problem for PET Bottle Collection

José-Fernando Camacho-Vallejo *, Eva Selene Hernández-Gress , Carlos Corpus , Ali Zahedi

Tecnologico de Monterrey, Escuela de Ingeniería y Ciencias, Monterrey, México,
fernando.camacho@tec.mx, evahgress@tec.mx,
carlos.corpus@tec.mx, a00835541@tec.mx,
* Presenting author.

Keywords: Location, Routing, Bilevel Optimization, Matheuristics

Introduction

Plastic waste, particularly from PET bottles, has become a major environmental concern due to its widespread use and slow degradation. Efficient collection systems play a crucial role in redirecting PET waste from landfills or collection centers to recycling facilities, where it can be processed into new products [5]. The location of collection centers for recycling has attracted the attention of researchers in recent years (e.g., [1], [4]), as has the optimization of recycling routes (e.g., [3]).

In this study, we address a problem in which a recycling company seeks to establish PET bottle collection facilities to encourage individuals to drop off PET bottles from domestic use. Additionally, individuals will receive a financial incentive based on the amount of PET they deposit. The recycling company must determine the price paid per kilogram of collected PET at each facility.

Based on an estimate of the incentive they will receive, individuals decide whether to recycle. After each period in the planning horizon, the recycling company designs a routing plan to transport the collected PET from the facilities to a treatment plant. At the treatment plant, the PET undergoes recycling and is transformed into small pellets, which are then sold to a different market.

The recycling company's objective is to maximize profit, which is calculated as the revenue from selling recycled pellets minus operational costs, including those associated with facility location and routing.

It is important to emphasize that individuals will recycle only if the incentives offered are beneficial to them. Therefore, we employ a bilevel optimization approach to model this location-routing problem with pricing decisions. Since individuals are not obligated to recycle, their autonomy in the decision-making process is evident, which justifies the proposed approach.

Location, routing, and pricing decisions are made at the upper level. Location decisions are determined using a GRASP. Once the locations of some collection facilities have been selected, the structure of the lower-level problem can be exploited, allowing the optimal pricing policy set by the recycling company to be obtained analytically. Consequently, this approach avoids solving an embedded problem to determine the lower-level response. At this stage of the solution methodology, the amount of collected PET at each facility is known. Therefore, routing decisions are obtained using a commercial solver. After an initial solution is constructed, a local search is applied to improve it. This scheme is embedded in an iterative procedure, leading to a matheuristic algorithm. For a more in-depth discussion of matheuristic algorithms, the reader is referred to [2].

To validate the proposed approach, a realistic case study from Mexico City is analyzed. The results provide relevant managerial insights. Additionally, a sensitivity analysis is conducted on the number of facilities to be located. The presentation concludes with promising ideas for future research directions.

Bibliography

[1] Ayyildiz, E. and Erdogan, M. A decision support mechanism in the determination of organic waste collection and recycling center location: A sample application for Turkiye. *Applied Soft Computing*, 147, 110752, 2023.

[2] Boschetti, M. A. and Maniezzo, V. Matheuristics: using mathematics for heuristic design. *4OR*, 20(2), 173-208, 2022.

[3] Hess, C., Dragomir, A. G., Doerner, K. F., and Vigo, D. Waste collection routing: a survey on problems and methods. *Central European Journal of Operations Research*, 32(2), 399-434, 2024.

[4] Purkayastha, D., Majumder, M., and Chakrabarti, S. Collection and recycle bin location-allocation problem in solid waste management: A review. *Pollution*, 1(2), 175-191, 2015.

[5] Schmidt, S., Laner, D., Van Eygen, E., and Stanisavljevic, N. Material efficiency to measure the environmental performance of waste management systems: A case study on PET bottle recycling in Austria, Germany and Serbia. *Waste Management*, 110, 74-86, 2020.

New Mathematical Models of Clustered Vehicle Routing Problem for the Waste Collection Process

Yaren Çelik [a,*], Kumru Didem Atalay [a], Berna Dengiz [a], Tusan Derya [a], Bahar Yetiş Kara [b]

[a] Başkent University, yarencelik@baskent.edu.tr, katalay@baskent.edu.tr, bdengiz@baskent.edu.tr, tderya@baskent.edu.tr
[b] Bilkent University, bkara@bilkent.edu.tr
[*] Presenting author.

Keywords: Vehicle Routing, Transportation, Mathematical Programming

Abstract

Waste management is a process that involves the collection, transportation, recycling, and disposal of waste to protect the environment and ensure the efficient use of resources. Within this domain, logistics optimization is a critical component that directly influences operational efficiency and cost effectiveness. The Vehicle Routing Problem (VRP) is a combinatorial optimization problem that aims to plan the most efficient distribution of goods or collection of waste from one or more depots to specific locations. VRP, which is classified as an NP-hard problem, has many real-world applications, including school bus routing, fuel distribution, newspaper and mail delivery, retail product distribution, and waste collection.

Due to the variability of real-world scenarios, several variants of the VRP have been developed. One such variant is the Clustered Vehicle Routing Problem (CluVRP), which groups customers or collection points into predetermined clusters and determines the most optimal routes for vehicles. An extension of this model, the Soft Clustered Vehicle Routing Problem (Soft CluVRP), relaxes the constraint of single-entry cluster traversal, permitting multiple entries and exits. This added flexibility provides significant advantages, particularly in waste collection processes, by reducing operational costs and improving overall efficiency.

This study addresses a real-world problem that involves the collection of waste from specific healthcare institutions and its transportation to a waste collection center. Mathematical models have been developed for two distinct routing approaches, and their solutions have been obtained. Sensitivity analyses were also performed to examine the effects of changes in the model parameters.

Bibliography

[1] Battarra, M., Erdoğan, G., and Laporte, G. (2014). A branch-and-cut algorithm for the clustered vehicle routing problem. *Computers & Operations Research*, **43**, 75–83. https://doi.org/10.1016/j.cor.2013.09.004

[2] Battarra, M., Erdoğan, G., and Vigo, D. (2014). Exact algorithms for the clustered vehicle routing problem. *Operations Research*, 62, 58–71. https://doi.org/10.1287/opre.2013.1227

[3] Defryn, C., and Sörensen, K. (2017). A two-level variable neighborhood search for the soft clustered vehicle routing problem. *Computers & Operations Research*, 78, 226–234. https://doi.org/10.1016/j.cor.2016.09.018

[4] Defryn, C., and Sörensen, K. (2017). A fast two-level variable neighborhood search for the clustered vehicle routing problem. *Computers & Operations Research*, 83, 78–94. https://doi.org/10.1016/j.cor.2017.02.007

[5] Heßler, K., and Irnich, S. (2021). A branch-and-cut algorithm for the soft-clustered vehicle-routing problem. *Discrete Applied Mathematics*, 288, 218–234. https://doi.org/10.1016/j.dam.2020.12.015

[6] Heßler, R., and Irnich, S. (2021). Symmetric modeling and solution methods for the soft clustered vehicle routing problem. *INFORMS Journal on Computing*, 33(2), 597–617. https://doi.org/10.1287/ijoc.2020.0961

[7] Hintsch, J. (2021). Multi-neighborhood local search for the soft clustered vehicle routing problem. *Computers & Industrial Engineering*, 157, 107305. https://doi.org/10.1016/j.cie.2021.107305

[8] Hintsch, T., and Irnich, S. (2020). Exact solution of the soft-clustered vehicle-routing problem. *European Journal of Operational Research*, 280(1), 164–178. https://doi.org/10.1016/j.ejor.2019.10.008

[9] Horvat-Marc, A., Marichel, M., and Tavakkoli-Moghaddam, R. (2017). Metaheuristics for the clustered vehicle routing problem: A comparative study. *Journal of Heuristics*, 23(5), 287–310. https://doi.org/10.1007/s10732-017-9332-2

[10] Toth, P., and Vigo, D. (2014). *Vehicle Routing: Problems, Methods, and Applications* (2nd ed.). Society for Industrial and Applied Mathematics (SIAM).

[11] Vidal, T., Battarra, M., Subramanian, A., and Erdoğan, G. (2015). Hybrid metaheuristics for the clustered vehicle routing problem. *Computers & Operations Research*, 58, 87–99. https://doi.org/10.1016/j.cor.2015.02.004

[12] Zhou, Y., Liu, L., Benlic, U., Li, Z.-C., and Wu, Q. (2025). Solving soft and hard-clustered vehicle routing problems: A bi-population collaborative memetic search approach. *European Journal of Operational Research*, 324(3), 825–838. https://doi.org/10.1016/j.ejor.2025.02.021

[13] Zhou, Y., Qu, C., Wu, Q., Kou, Y., Jiang, Z., and Zhou, M. (2024). A bi-level hybrid iterated search approach to soft-clustered capacitated arc routing problems. *Transportation Research Part B: Methodological*, 184, 102944. https://doi.org/10.1016/j.trb.2024.102944

[14] Zhou, Y., Wang, H., and Sörensen, K. (2025). A co-evolutionary population-based algorithm for the soft clustered vehicle routing problem. *Transportation Science*, Advance online publication.

A bilevel model for locating garment recycling bins

Dámaris Arizhay Dávila Soria [a,*], Mario Alberto Aguirre-López [b], Jose-Fernando Camacho-Vallejo [c]

[a] Universidad de los Andes, Faculty of Engineering and Applied Sciences, Chile, daavilas@uandes.cl,
[b] Autonomous University of Chiapas, Faculty of Sciences in Physics and Mathematics, Mexico, marioal1906@gmail.com
[c] Tecnológico de Monterrey, Escuela de Ingeniería y Ciencias, Mexico, fernando.camacho@tec.mx
[*] Presenting author.

Keywords: Bilevel, Location, Clothing recycling

Introduction

In recent decades, sustainability has become increasingly relevant in supply chain management [1]. As one of the response, the circular supply chain (CSC) concept has emerged, aiming to extend product life cycles through strategies such as recycling and reuse. A key aspect of the recycling process is the strategic location of recycling infrastructures, such as collection centers and drop-off points, which are important in improving system efficiency [2]. Several studies have explored the bin location problem for different recyclable materials, considering material hazards, social accessibility, logistics costs, and other critical aspects (see [4, 3]). One particular area of focus is the textile industry, where the rise of fast fashion has led to excessive clothing disposal, often before garments reach the end of their life. For this reason, it is crucial to develop strategies that optimize collection while also facilitating textile reintegration without relying on chemical processes. To address that challenge, this work proposes a strategy for locating textile waste collection bins, considering accessibility for the population. In addition, one possible approach to enhance the CSC is to allocate collected garments from these bins to local remanufacturers specializing in upcycling, who reuse discarded textiles based on their condition. Integrating local remanufacturers specialized in upcycling facilitates the direct reinsertion of garments into new production cycles, reducing dependency on resource-intensive recycling methods, and minimizing textile waste accumulation in landfills.

Problem description

We consider a private recycling company responsible for collecting garments. This company gathers garments in any condition by strategically placing collection bins across the city. Assuming that individuals donating their garments do not seek any financial incentives, the placement of collection bins should prioritize accessibility to encourage participation. The garments collected in each bin are then purchased by local re-manufacturing companies, which have minimum and maximum budgets to ensure business viability and align with their investment capacities, while also considering the profits they will generate from using the garments purchased from each bin. In this context, two interrelated decision levels are involved: one associated with the recycling company, and the other with the re-manufacturing companies. In the first one, the recycling company is responsible for locating collection bins to accumulate garments. This company seeks to maximize its profit, which is defined as the income from the sales of collected garments. In the second level, re-manufacturing companies aim to maximize their profit by purchasing the bins from the recycling company. Re-manufacturers offer a price per bin, which depends on transportation costs to their facilities and the expected 'quality' of the bins. The term 'quality' refers to a subjective measure perceived by re-manufacturers based on the bin's location, which influences the projected profits from selling the new products made from the garments in each bin, depending on their specialization. Consequently, re-manufacturers may place different bids for the same bin. This problem is formulated as a bilevel programming model, where decision-makers interact in a hierarchical structure. At the upper level, the collection company acts as the leader, seeking to maximize profit from selling the collected clothing. At the lower level, independent remanufacturers act as followers, aiming to maximize their profit from purchasing the garments collected in the bins. The garment collected in each bin is assigned in their entirety to a remanufacturer, ensuring that the minimum and maximum demand constraints of each remanufacturer are met.

Solution method and results

Since we have a bilevel programming problem with A linear lower level, the model can be reformulated into a single level problem. Then, we deal with this by using Karush-Kuhn-Tucker conditions and proposing two metaheuristics to solve the resulting model. To validate our method, we performed a deep comparative study between the implemented algorithms, looking to compare computational efficiencies and the quality of the solutions. Finally, we apply our model to a case study in Santiago, Chile, where we analyze the trade-off between maximizing the recycling company's profit, strengthening the link with local remanufacturers, and minimizing the environmental impact of the collected garments. Through this analysis, we highlight key insights that can guide more sustainable and economically viable decision-making in textile recycling.

Bibliography

[1] Koberg, E. and Longoni, A. A systematic review of sustainable supply chain management in global supply chains. *Journal of Cleaner Production*, 207, 1084–1098, 2019.

[2] Nevrlỳ, V., Šomplák, R., Smejkalová, V., Lipovskỳ, T., and Jadrnỳ, J. Location of municipal waste containers: Trade-off between criteria. *Journal of Cleaner Production*, 278, 123445, 2021.

[3] Rousta, K., Bolton, K., Lundin, M., and Dahlén, L. Quantitative assessment of distance to collection point and improved sorting information on source separation of household waste. *Waste Management*, 40, 22–30, 2015.

[4] Viktorin, A., Hrabec, D., Nevrlý, V., Šomplák, R., and Šenkeřík, R. Hierarchical clustering-based algorithms for optimal waste collection point locations in large-scale problems: A framework development and case study. *Computers & Industrial Engineering*, 178, 109142, 2023.

[5] Jia, F., Yin, S., Chen, L., and Chen, X. The circular economy in the textile and apparel industry: A systematic literature review. *Journal of Cleaner Production*, 259, 120728, 2020.

Towards more sustainable Postal Supply Chains: a probabilistic approach to design Last-Mile Delivery Areas

Giuseppe Bruno , Antonio Diglio *, Carmela Piccolo , Eduardo Pipicelli

University of Naples Federico II, Naples, Italy
giuseppe.bruno@unina.it, antonio.diglio@unina.it, carmela.piccolo@unina.it
eduardo.pipicelli@unina.it
* Presenting author.

Keywords: Last-mile Logistics, Sustainable Supply Chain, Delivery Areas Design

Introduction

The growth of e-commerce is motivating the development of innovative solutions for efficient and sustainable supply chains in the B2C parcel delivery market. Particularly, the focus is on the last-mile logistics as the crucial phase. In this context, self-collection is a recent but consolidated delivery strategy, allowing customers to autonomously collect parcels from dedicated facilities, such as pick-up points ([1], [2]). Reduced reliance on home delivery allows for the consolidation of parcels at these points, likely decreasing the number of operators need to visit, lowering their daily workload, and generating cost savings. Accordingly, (i) the reorganization of delivery operations based on pick-up point location scenarios and (ii) the quantification of the associated economic impacts emerge as two relevant issues.

To address these, this study presents a practical methodological proposal for the *design of delivery areas* in last-mile contexts. Notably, the organization of service areas in distribution logistics is a consolidated practice. This is commonly approached by resorting to *territory design/districting* methodologies ([3]). In the literature, several successful examples of districting applications in distribution logistics are found ([4], [5]). Nevertheless, studies that include explicit routing considerations are limited, and, to the best of our knowledge, none of the available works account for the uncertainties associated with daily visit probabilities at customer nodes and pick-up points.

In fact, creating stable and robust territories may be a preferable alternative to solving operational routing. As routes to visit all the customers requiring a parcel may vary from day to day, a more tactical posture is convenient. The overall area to be served (e.g., a city) can be grouped into a given number of delivery areas (the *districts*), each assigned to a specific operator. This way, operators may follow a predefined routing plan—which they adjust dynamically based on customers' daily appearances (skipping those that must not be served)—or organize their daily tours from scratch based on deterministic customer information. Furthermore, such a districting approach enhances operators' *familiarity* with their zones, which improves their performance and heightens customer satisfaction in the mid-to-long run. In fact, as the operator becomes familiar with his zone, he enhances his ability to find customers and, ultimately, his overall performance.

In this context, our research introduces a novel districting procedure that, alongside other typical planning criteria, accounts for *workload requirements*. As a practical condition, the latter ensures that the expected workload in each district remains within specified limits—namely, that daily deliveries are completed in a maximum amount of time. The workload includes the time required to travel, stop, and serve all points within the district (i.e., customers and pick-up points). Thus, it reflects the day-to-day operators' effort under a combination of home delivery and self-collection strategies. The approach accounts for uncertainty associated with customer preferences toward the strategies with the aim of assessing the impact of different pick-up point network configurations on delivery costs.
The procedure is applied to the case study of the city of Bologna (Italy), using fine-grained information on customers' locations and historical data on delivery volumes. Results from the experiments highlight the value of self-collection, showing the impact of pick-up points' presence in reducing the workforce required to perform daily deliveries and, hence, the associated costs. In addition, we also demonstrate the robustness of the obtained reorganization solutions against varying operational settings and projected delivery volumes. This way, we intend to propose a methodological approach that, beyond its scientific contributions, provides actionable insights enhancing the decision-making practice.

Bibliography

[1] Boysen, N., Fedtke, S., and Schwerdfeger, S. Last-mile delivery concepts: a survey from an operational research perspective. *Or Spectrum*, 43(1), 1-58, 2021.

[2] Rohmer, S. and Gendron, B. A guide to parcel lockers in last mile distribution: Highlighting challenges and opportunities from an OR perspective. *Cirrelt Montreal*, 11, 2020.

[3] Kalcsics, J. and Rios-Mercado, R. Z. Location science. *Springer*, 705–743, 2019.

[4] Sandoval, M. G., Alvarez-Miranda, E., Pereira, J., Ríos-Mercado, R. Z. and Diaz, J. A A novel districting design approach for on-time last-mile delivery: An application on an express postal company. *Omega*, 113, 102687, 2022.

[5] Álvarez-Miranda, E. and Pereira, J. A districting application with a quality of service objective. *Mathematics*, 10(1), 13, 2022.

The Maximum Capture Facility Location with Random OWA Utilities

Concepción Domínguez [a,*], Ricardo Gázquez [b], Juan Miguel Morales [c], Salvador Pineda [c]

[a] University of Murcia, concepcion.dominguez@um.es
[b] University of Granada, rgazquez@ugr.es
[c] University of Málaga, juan.morales@uma.es, spineda@uma.es,
[*] Presenting author.

Keywords: EWGLA2025, Combinatorial Optimization, Cooperative Maximal Covering, Ordered Median function

Introduction

In the Maximal Covering Location Problem (MCLP) [4], a company places a number of facilities to maximize the demand covered. Each demand node is covered if the closest facility is within a predetermined radius. In the cooperative version of the problem (CMCLP) [1], the installed facilities cooperate to increase the attraction of customers to the company. In this sense, a demand node is covered if the aggregated partial attractions (or partial coverings) of open facilities exceed a threshold. In this work, we generalize the CMCLP introducing an Ordered Median function (OMf), a function that assigns importance weights to the sorted partial attractions of each customer, and then aggregates the weighted attractions to provide the total level of attraction. We name this problem the Ordered Cooperative Maximum Covering Location Problem (OCMCLP). The OMf serves as a means to compute the total attraction of each customer to the company as an aggregation of ordered partial attractions and constitutes a unifying framework for CMCLP models. Other types of covering problems have also been generalized using the OMf ([2, 3])

We introduce a multiperiod stochastic non-linear formulation for the OCMCLP with an embedded assignment problem characterizing the OMf. For this model, we present two exact solution approaches: a MILP reformulation with valid inequalities and a well-known Benders' decomposition approach. The performance of the models is tested using random instances and the quality of the solutions compared with the classical CMCLP is illustrated with a case study of locating charging stations to maximize electric vehicle adoption in the city of Trois-Rivières, Québec (Canada).

Bibliography

[1] Berman, O., Drezner, Z., and Krass, D. Cooperative cover location problems: The planar case. *IIE Trans.* 42 (3), 232–246, 2009.

[2] Blanco, V. and Gázquez, R. Fairness in maximal covering location problems. *Computers and Operations Research.* 157, 106287, 2023.

[3] Blanco, V. and Puerto, J. Covering problems with polyellipsoids: A location analysis perspective. *European Journal of Operational Research* 289 (1), 44–58, 2021.

[4] Church, R. and ReVelle, C. The maximal covering location problem. In: *Papers of the Regional Science Association*, vol. 32, Springer-Verlag Berlin/Heidelberg, pp. 101–118, 1974.

Enforcing Stability in Capacitated Facility Location Problems with Ordinal Customer Preferences

Adam Dunajski [*]**, Sergio García , Akshay Gupte**

University of Edinburgh, A.Dunajski@sms.ed.ac.uk, sergio.garcia-quiles@ed.ac.uk, akshay.gupte@ed.ac.uk
[*] Presenting author

Keywords: Location Analysis, Game Theory, Mixed Integer Linear Programming

Facility Location Problems are well studied in the literature of Operational Research. They involve selecting a set of facilities to open from a set of candidate locations J incurring fixed opening costs. An allocation, incurring allocation costs, of a set of customers I to the facilities is then proposed such that the demand of each customer is satisfied.

Classically both the choices of location and customer allocation are completed by a central decision maker, and customers cannot choose among the open facilities. However customer preferences may not align with those of the decision maker. Here customers can act as strategic agents and deviate from a proposed allocation. Such freedom of choice is present, for example, in school choice in the UK. Here parents have a right to express preferences over state schools, and all schools (except grammar schools) must offer a place to every child who has applied if they have space.

To address this, we are required to incorporate known ordinal customer preferences into integer linear programming formulations. For each customer $i \in I$ we consider *preferences relation* $\succ_i$. For candidate locations $j, j' \in J$ we say customer i prefers location j to location j' if and only if $j \succ_i j'$. This notation is extended to $j \succeq_i j'$ with equality holding if and only if $j = j'$. The uncapacitated variant of this problem is addressed by Hanjoul and Peeters [1]. Their model uses decision variables x_{ij} to represent the proportion of customer i's demand allocated to location j, incuring an allocation cost of c_{ij}, and binary decision variables y_j to represent a facility being opened at location j incurring a fixed cost f_j. They proposed the following formulation.

$$
\begin{aligned}
\text{Min.} \quad & \sum_{j\in J} f_j y_j \ \sum_{i\in I}\sum_{j\in J} c_{ij}x_{ij} \\
\text{s.t.} \quad & \sum_{j\in J} x_{ij} = 1 \quad \forall i \in I, && (1)\\
& x_{ij} \leq y_j \quad \forall i \in I \forall j \in J, && (2)\\
& \sum_{j':j'\succeq_i j} x_{ij'} \geq y_j \quad \forall i \in I, \forall j \in J, && (3)\\
& x_{ij} \geq 0 \quad \forall i \in I, \forall j \in J,\\
& y_j \in \{0,1\} \quad \forall j \in J.
\end{aligned}
$$

Subsequent work based on their paper has focused on strengthening this formulation through the development of valid in equalities [2].

However less work has focused on incorporating customer demands and facility capacities into the model. When considering the capacitated setting one must decide if the allocation variables x_{ij} should be forced to take binary values. In forcing these to be binary, we stipulate that each customer must have their demand fully allocated to exactly one location. This is referred to in the literature as a *single-source* allocation. Otherwise when x_{ij} can take fractional values, we allow for any given customer's demand to be split between multiple locations. Both variants of the problem have been identified in recent literature [3][4].

Although capacities and demands can be incorporated into constraints (1) and (2), we must consider if the constraints (3) still model a desirable solution concept. This issue will be discussed in our presentation.

Our work incorporates solution concepts from the algorithmic game theory and stable matching communities including Nash stability and swap stability, into the capacitated problem. Both single-source and fractional allocations are considered.

We propose new integer linear programming formulations which enforce these notions of stability and demonstrate their performance on benchmark instances.

Bibliography

[1] Hanjoul, P. and Peeters, D. A facility location problem with clients' preference orderings. *Regional Science and Urban Economics* 17(3), 451-473, 1987.

[2] Cánovas, L., García, S., Labbé, M., and Marín, A. A strengthened formulation for the simple plant location problem with order. *Operations Research Letters* 35(2), 141-150, 2007.

[3] Kang, C.-N., Kung, L.-C.,Chiang, P.-H., and Yu, J.-Y. A service facility location problem considering customer preference and facility capacity. *Computers & Industrial Engineering* 177, 109070, 2023.

[4] Büsing, C., Leitner, M., and Wrede, S. Cover-based inequalities for the single-source capacitated facility location problem with customer preferences *Optimization Online* 2024.

A Multi-Objective Mixed Integer Linear Programming Model for In-Motion Charging Location Planning

Mohammad Javad Eslami *, **Thomas Byrne**, **Mahdi Doostmohammadi**

University of Strathclyde, United Kingdom
mohammad-javad.eslami@strath.ac.uk, tom.byrne@strath.ac.uk,
m.doostmohammadi@strath.ac.uk
* Presenting author.

Keywords: Discrete Location, Electric Vehicle Charging Infrastructure, Multi-Objective Mixed Integer Linear Programming

Introduction

The global transportation sector is undergoing a significant transformation as nations strive to address energy crises, reduce carbon emissions, and combat climate change. In this context, electric vehicles (EV) have emerged as a promising solution, offering energy-saving and zero-emissions advantages over traditional internal combustion engine vehicles.

Governments around the world have implemented various policies, such as subsidies, tax incentives, and public charging infrastructure programs, to accelerate the adoption of EVs. However, despite these efforts, widespread adoption of EVs remains hindered by several critical challenges, including limited driving range, long charging times, and the high cost of batteries. These issues contribute to range anxiety, a significant barrier for potential EV consumers.

To address these limitations, in-motion charging systems have been proposed as a revolutionary solution. The system enables EVs to charge wirelessly while in motion, using inductive power transfer systems embedded in roadways. This technology alleviates range anxiety by providing continuous energy replenishment and also allows the use of smaller, more cost-effective batteries, further reducing the EV's overall costs; a key barrier to EV's global adoption.

In-motion charging system has been successfully deployed in several countries on different types of electric roads (either intersections, urban or national highways), such as Germany [1], Sweden [1], South Korea [1], Japan [3], New Zealand [4], and the United States of America [5], showcasing their potential to revolutionise EV infrastructure. However, the deployment of the systems has some major challenges, including high construction costs of charging infrastructure and the need for strategic placement to maximise captured EV flow.

In addition, the integration of in-motion charging systems into existing road networks requires careful consideration of factors such as traffic flow, road capacity, and driver behavior. For instance, the presence of charging lanes can lead to reduced road capacity and increased traffic congestion, particularly in urban areas with limited lane availability. Despite these challenges, the potential benefits of in-motion charging technology are undeniable. By optimising the deployment of the systems, it is possible to enhance network efficiency and promote widespread adoption of EVs.

The Problem

This research aims to develop an optimisation framework to strategically determine optimal locations for in-motion wireless charging infrastructure within road networks to enhance its effectiveness in supporting EV adoption.

While previous research has explored various aspects of wireless charging for EVs, existing studies often focus on either minimising infrastructure costs [1, 4, 5] or maximising total captured flow [2, 3, 6] without integrating a comprehensive bi-objective approach. Hence, our research bridges this gap by proposing a novel bi-objective mixed-integer linear programming model that simultaneously minimises infrastructure costs and maximises the volume of EVs that can effectively utilise the charging infrastructure (referred to as "captured EV flow").

In addition, our model incorporates practical constraints that reflect real-world challenges in in-motion charging implementation. These include identifying areas where deployment is restricted due to environmental, technological, or urban planning considerations, as well as ensuring that EVs have a pre-decided satisfactory battery level upon exiting the charging network. Maintaining a sufficient charge level is critical for user confidence and practical usability, as drivers need assurance that they can reach their destinations without running out of power. Unlike previous studies, which have typically overlooked this factor or assumed unlimited charging availability such as [4, 6], our model is able to provide a more realistic solution by incorporating these constraints. Finally, to validate the proposed model, numerical experiments will be conducted on a Scottish road network.

Bibliography

[1] Chen, Z., Liu, W., and Yin, Yafeng. Deployment of stationary and dynamic charging infrastructure for electric vehicles along traffic corridors. *Transportation Research Part C: Emerging Technologies*, 77, 185-206, 2017.

[2] He, J., Yang, H., Tang, T. Q., and Huang, H. J. Optimal deployment of wireless charging lanes considering their adverse effect on road capacity. *Transportation Research Part C: Emerging Technologies*, 111, 171-184, 2020.

[3] Honma, Y., Hasegawa, D., Hata, K., and Oguchi, T. Locational Analysis of In-motion Wireless Power Transfer System for Long-distance Trips by Electric Vehicles: Optimal Locations and Economic Rationality in Japanese Expressway Network. *Networks and Spatial Economics*, 24(1), 261-290, 2024.

[4] Majhi, R. C., Ranjitkar, P., and Sheng, M. Optimal allocation of dynamic wireless charging facility for electric vehicles *Transportation Research Part D: Transport and Environment*, 111, 103461, 2022.

[5] Mubarak, M., Üster, H., Abdelghany, K., and Khodayar, M. Strategic network design and analysis for in-motion wireless charging of electric vehicles. *Transportation Research Part E: Logistics and Transportation Review*, 145, 102179, 2021.

[6] Riemann, R., Wang, D. Z., and Busch, F. Optimal location of wireless charging facilities for electric vehicles: Flow-capturing location model with stochastic user equilibrium. *Transportation Research Part C: Emerging Technologies*, 58, 1-12, 2015.

New mixed-integer linear models for the 2-Layer Straight Line Crossing Minimization Problem

Inmaculada Espejo [a,*], **Mercedes Landete** [b], **Juanjo Peiró** [c]

[a] Universidad de Cádiz, Spain, inmaculada.espejo@uca.es,
[b] Universidad Miguel Hernández de Elche, Spain, landete@umh.es
[c] Universitat de València, Spain, juanjo.peiro@uv.es
[*] Presenting author.

Keywords: edge crossing, mixed integer linear programming, Layered graphs

Layered graphs, where nodes are assigned to distinct layers and edges connect nodes between layers, are widely used to represent sequential and hierarchical relationships across various fields, including machine learning, biology and humanities. One of the most important aesthetic criterion for the readability of a graph is the minimization of straight line crossings. This consists of positioning the nodes in each layer so that the number of crossings between edges, when drawn as straight lines, is minimized. A crossing occurs when two edges intersect at a point that is not a node. The crossing number is entirely dependent on the ordering of nodes within each layer.

Drawing graphs with minimum number of cuts has significant applications in graph visualization, network analysis and information retrieval, where the readability and interpretability of graph layouts are crucial [5], as well as in computational biology, VLSI design, data mining and pattern recognition, among others [1, 14]. Moreover, their solutions can be used to solve the rank aggregation problem that has applications in meta-search and spam reduction on the Web [2].

In this paper, we focus on the Two-Layer Straight Line Crossing Minimization (2L-SLCM) problem ([8, 9]). This problem is also called two-sided or bipartite graph crossing minimization problem. The nodes of the graph are partitioned into two layers, the edges connect nodes on the layers and the goal is to find the nodes orderings (in the two layers) that minimize the number of crossings. This problem is NP-hard [6], even for simple graphs or fixing the upper layer. For this reason, the design of heuristics and approximation algorithms is the focus of much of the related research (see [8, 10, 12] for a experimental comparison of crossing minimization heuristics). We are interested in exact approaches to the problem that prioritize human readability over computational scalability. The first integer linear programming model of the 2L-SLCM was proposed by Jünger et al. [7]. A common approach is to model this problem as a binary quadratic programming problem and then linearize the quadratic terms by introducing new variables [3, 15]. Semidefinite programming relaxations have been studied in [4]. Different branch-and-bound algorithms have been proposed [13].

The objective of this research is twofold: i) to improve the efficiency of the current exact solution methods for the 2L-SLCM problem by reinforcing existing formulations with new valid inequalities and preprocessing techniques that reduce formulation size; and ii) to propose several new MILP formulations, based on different modeling approaches, and to exploit different properties of the problem structure. We introduce new decision variables and constraints that aim to reduce the size of the formulations and improve their linear programming relaxations. New branch-and-cut methods are proposed to solve the problem.

Bibliography

[1] Abdullah, A. Robust clustering by double bisection crossing minimization. *Appl. Comput. Math.*, 9, 4-18, 2010.

[2] Biedl, T., Brandenburg, F.J., and Deng, X. Crossings and permutations. In: Healy, P., Nikolov, N.S. (eds.) *Proceedings of Graph Drawing*, 1–12, 2005.

[3] Buchheim, C., Wiegele, A., and Zheng L. Exact algorithms for the quadratic linear ordering problem *INFORMS J. Comput.*, 22 (1), 168-177, 2010.

[4] Chimani, M., Hungerländer, P., Jünger, M., and Mutzel, P. An SDP approach to multi-level crossing minimization. *ACM J. Exp. Algorithmics*, 17 (3), 1-26, 2012.

[5] Di Battista, G., Eades, P., Tamassia, R., and Tollis, I. Graph Drawing: Algorithms for the Visualization of Graphs. Prentice Hall, 1999.

[6] Garey, M. R. and Johnson, D. S. Crossing Number is NP-Complete. *SIAM Journal on Algebraic Discrete Methods*, 4(3), 312-316, 1983.

[7] Jünger, M., Lee, E.K., Mutzel, P., and Odenthal T. A polyhedral approach to the multi-layer crossing minimization problem. G. Di Battista (Ed.), *Graph Drawing9́7, Lecture Notes in Computer Science*, 1353, Springer, Berlin, Heidelberg, pp. 13-24, 1997.

[8] Jünger, M. and Mutzel, P. 2-layer straight line crossing minimization: performance of exact and heuristic algorithms. *Journal of Graph Algorithms and Applications*, 1(1), 1–25, 1997.

[9] Laguna, M. and Marti, R. GRASP and path relinking for 2-layer straight line crossing minimization. *INFORMS J. Comput.* 11 (1): 44–52, 1999.

[10] Martí, R. and Laguna, M. Heuristics and meta-heuristics for 2-layer straight line crossing minimization. *Discret. Appl. Math.*, 127 (3), 665-678, 2003.

[11] Martí, R. A tabu search algorithm for the bipartite drawing problem. *Eur. J. Oper. Res.*, 106 (2–3), 558-569, 1998.

[12] Stallmann, M., Brglez, F., and Ghosh, D. Heuristics, experimental subjects, and treatment evaluation in bigraph crossing minimization. *ACM J. Exp. Algorithmics*, 6, 1-42, 2001.

[13] Valls, V., Marti, R., and Lino, P. A branch and bound algorithm for minimizing the number of crossing arcs in bipartite graphs. *European Journal of Operational Research*, 90(2), 303–319, 1996.

[14] Wotzlaw, A., Speckenmeyer, E., and Porschen, S. Generalized k-ary tanglegrams on level graphs: a satisfiability-based approach and its evaluation. *Discret. Appl. Math.*, 160 (16–17) 2349-2363, 2012.

[15] Zheng L. and Buchheim, C. A new exact algorithm for the two-sided crossing minimization problem A. Dress, Y. Xu, B. Zhu (Eds.) *Combinatorial Optimization and Applications, Lecture Notes in Computer Science*, 4616, Springer, Berlin, Heidelberg, pp. 301-310, 2007.

The Multiple-Picker Order Assigment Routing Problem

Elena Fernández [a,*], Manuel Munoz-Marquez [a], Jessica Rodríguez-Pereira [b]

[a] Department of Statistics and Operation Research, Universidad de Cádiz,
elena.fernandez@uca.es, manuel.munoz@uca.es
[b] Department of Statistics and Operation Research, Universitat Politècnica de Catalunya,
jessica.rodriguez@upc.edu
[*] Presenting author.

Keywords: Steiner Traveling Salesman Problem, Integer Linear Programming, Branch-and-Cut.

Introduction

In this presentation we address the Multiple-Picker Order Assignment Routing Problem (M-POARP). The M-POARP belongs to the class of Order Routing Problems, which, broadly speaking, aim to determine efficient routes to pick up orders in warehouses. The distinctive characteristics of the M-POARP are: *i* orders are picked by a set of pickers (instead of just one) and *ii* it considers a balancing objective for the cost of the routes, instead of focusing on the overall cost of all routes.

The M-POARP is defined over a given warehouse where the operations take place. There is a set of orders that must be *collected* by a given set of pickers. Orders consist of one or more items, located at different places in the warehouse. The orders are partitioned into picking batches and each order is fully assigned to exactly one batch. Each picker collects at most one batch, and the route to be performed by each picker must be determined. All routes start and end at a common depot d.

We assume that the warehouse consists of a set of disjoint *picking aisles* where the items conforming the orders are located at racks, plus a set of *crossing aisles* connecting the picking aisles. After some preprocessing, we model the layout of the warehouse as an undirected connected graph $G = V, E$, with $V = V_O \cup V_N \cup \{d\}$ where V_O is the set of vertices of the picking aisles and V_N is the set of vertices of the crossing aisles. E contains the edges connecting every pair of neighboring points.

We exploit the relationship of the M-POARP with a min-max variant of the Steiner TSP Problem (STSP) on $G = V, E$ with set of required vertices given by V_O, and propose an ILP formulation for the M-POARP based on the one introduced in [1] for the STSP. We study some properties of the M-POARP, which allow to derive optimality conditions and develop some families of inequalities based on them, which are specific for the M-POARP. We also introduce some new families of valid inequalities and adapt to the M-POARP existing families of valid inequalities. Finally, we summarize and analyze the numerical results of a branch-and-cut algorithm integrating the above ingredients, on a set of benchmark instances adapted from the literature.

Bibliography

[1] Rodríguez-Pereira, J., Fernández, E., Laporte, G., Benavent, E., and Martínez-Sykora, A. The Steiner traveling salesman problem and its extensions. *European Journal of Operational Research*, 278(2), 615–628, 2019.

A Stackelberg location game on the plane with equilibrium delivered prices

José Fernández [a,*], Boglárka G. Tóth [b]

[a] Dpt. Statistics and Operations Research, University of Murcia, Spain, josefdez@um.es,
[b] Dpt. Computational Optimization, University of Szeged, Hungary, boglarka@inf.szte.hu
[*] Presenting author.

Keywords: Competitive location, social cost, delivered prices, Stackelberg problem

Introduction

In this paper we consider the case of two competing chains that want to expand their presence in a given area of the plane. Both chains may already have some existing facilities operating in the area, selling a given product. And what the chains have to decide is not only where to locate their new facility, but also the price at which they are going to sell the product to each demand point where customers are assumed to be concentrated. A delivered pricing policy is followed by both firms, i.e., the price offered by a chain to a given demand point include both production costs and transportation costs. Customers buy at the facility offering the lowest price. When the locations of the facilities are fixed, a price equilibrium exists. In particular, the equilibrium price to be set at a given demand point is the delivery cost of the facility with the second lowest delivery cost [2].

Assuming that price equilibria are used by both chains, the aim of this paper is to investigate the Stackelberg or leader-follower or $1|1$-centroid problem, i.e., we want to find the optimal location of the facility of the chain that locates first, known as the leader, anticipating that the competitor chain, the follower, will locate another single facility too, after the leader has done it.

When prices have been considered in the location literature it has always been in the context of Nash-equilibrium games. Usually, a refinement of the Nash equilibrium by using a two-stage process is considered. First, the chains *simultaneously* choose the locations for their facilities. And after that, the chains *simultaneously* choose the prices. The corresponding two-stage solution is called a subgame perfect Nash equilibrium. The subgame perfect Nash equilibrium is obtained by first obtaining the equilibrium prices (as a function of the location of the facilities), and then solving the game of simultaneously choosing the location of the facilities using as prices the equilibrium prices. So the location-price game is reduced to a location game with equilibrium prices. Solving the corresponding location game is also challenging. Lederer and Thisse [1] proved that in a duopoly with inelastic demand and constant marginal production costs, any global minimizer of the social cost (the total delivered cost if each customer is served with the lowest marginal delivered cost) is an equilibrium. This was used in [3] to solve the corresponding problem on the plane. Notice also that the solution of the leader-follower problem will be a location equilibrium for that game too, as neither of the

chains will have an incentive to move from their optimal locations.
Note, however, that the location game we deal with in this paper is different. We do not want to find a subgame perfect Nash equilibrium where prices and locations are chosen *simultaneously* by both chains. The aim is to solve the (1|1)-centroid problem, where customers are assumed to buy at the facility offering the lowest price. Hence, it is a *sequential* game: the leader locates first, and after that the follower locates. In particular, since we consider a delivered pricing policy, the equilibrium prices will be used to prevent modifications in the prices. So this other location-price game is also reduced to a location game with equilibrium prices. We want to highlight that this is a new continuous location model in the literature. As we will see, both the follower and the leader problems can be formulated as Mixed-Integer Non-Linear Programming problems (MINLP). A branch-and-bound procedure is used to cope with them. Some computational experiments are reported.
Interestingly, we will see that there may be problems for which the minimization points of the social cost are not optimal solutions of this new global optimization problem. This is different from the *simultaneous* location-price game [3, 1], where the minimization points of the social costs always were a solution of the problem (a subgame perfect Nash equilibrium).

Bibliography

[1] Lederer, P.J. and Thisse, J.F. Competitive location on networks under delivered pricing. *Operations Research Letters*, 9(91), 147-153, 1990.

[2] Pelegrín, B., Dorta-González, P., and Fernández, P. Finding location equilibria for competing firms under delivered pricing. *Journal of the Operational Research Society*, 2010.

[3] Fernández, J., Salhi, S., and Tóth, B. G. Location equilibria for a continuous competitive facility location problem under delivered pricing. *Computers & Operations Research*, 41(1), 185-195, 2014.

A Capacitated Discrete Competitive Facility Location and Design Model with Two Customers Choice Rules Sequentially Applied

Pascual Fernández [a,*], Algirdas Lančinskas [b], Julius Žilinskas [b]

[a] Department of Statistics and Operations Research, University of Murcia, pfdez@um.es
[b] Institute of Data Science and Digital Technologies, Vilnius University,
algirdas.lancinskas@mif.vu.lt, julius.zilinskas@mif.vu.lt
[*] Presenting author.

Keywords: Discrete competitive location, Location-design

Abstract

In this paper, we will consider a new firm that intends to establish its first facilities in a market area where other firms already provide services to customers. We will assume that the firm must choose the type of each facility from a discrete set of potential designs, and that, depending on the selected design, each facility will have a maximum capacity of customers it can accommodate. Therefore, we will consider a discrete competitive location and design problem with capacities.
Besides, two rules will be considered in the model, the binary and proportional rules, but their use will be sequential, i.e. we will take the proportional rule as priority rule when satisfying customer demand, considering the binary rule as secondary, so that only the binary rule will be applied when it is not possible to apply the proportional rule for the distribution of customer demand. Once all facilities, both preexisting and new, have been established, each customer's preferences are evaluated to determine if any facilities meet a pre-defined minimum attraction threshold. If such facilities are found, demand is allocated among them in proportion to the attraction the customer feels for each one (proportional rule). Conversely, if no facilities meet this minimum attractiveness criterion, the customer will fulfill their demand at the facility or facilities that offer the highest attraction (binary rule). In cases where multiple facilities share this maximum attraction (all falling short of the threshold for the proportional rule), the customer's demand will be evenly distributed among all of these facilities, whether they are pre-existing or newly established. In both cases, whether the proportional rule or the binary rule is applied, when allocating customers to the entering firm's facilities, their maximum capacities must be taken into account, which will depend mainly on the location and design chosen for these facilities.

Redesigning Italian health districts within new primary care regulatory frameworks

Giuseppe Bruno [a], Antonio Diglio [a], Andreana Ferraioli [b,*], Carmela Piccolo [a]

[a] University of Naples Federico II, Naples, Italy,
giuseppe.bruno@unina.it, antonio.diglio@unina.it, carmela.piccolo@unina.it
[b] University of Bergamo, Bergamo, Italy andreana.ferraioli@unibg.it
[*] Presenting author.

Keywords: Healthcare, Primary Healthcare, Service Districting

The contemporary global scenario is characterized by significant transformations in demographics and public health, with consequential repercussions for healthcare systems and societal structures.
The global population is now living longer, and the majority of people are in their sixties and beyond. Once confined to high-income countries, *population aging* is now affecting the entire world. [1] This demographic shift is accompanied by an increase in healthcare expenditures, attributable to an *increase in chronic diseases* and a growing demand for long-term care services. [2]
The combination of these factors, compounded by the challenges health systems face in recruiting and retaining staff, has resulted in a substantial *shortage of health workers* in most countries. [3]
This situation emphasises the necessity for a comprehensive *restructuring of healthcare systems* to address the aforementioned factors, a trend that has been observed in several countries. [4]
In the context of this reorganization, a pivotal function must be assumed by *primary healthcare*. This fundamental component of the healthcare system is expected to deliver reinforced prevention in order to improve early detection and long-term management of chronic conditions. This is intended to avoid the unnecessary use of hospital and specialist services, thereby reducing the burden on these services and preventing wasteful spending.[5]
In response to the aforementioned challenges, a variety of strategies have been implemented by different countries around the world. Of these, Italy has opted for the strengthening of the role of the *district* and the introduction or improvement, where similar structures already exist, of so-called *Community Healthcare Centers* (CHCs). The district is a territorial branch of the Local Health Authorities (LHAs), fulfilling a pivotal role in fostering integration among healthcare structures. It is responsible for guaranteeing a coordinated and continuous response to the population's needs, while also ensuring equal access to healthcare services. [6]
The Italian model for CHCs draws inspiration from the practices of other countries, namely healthcare agencies serving a defined population, integrated into the social tissue that provide a range of accessible, comprehensive, and integrated services. These services are grounded in the tenets of primary health care, which address prevailing health concerns and the underlying causes of poor health outcomes for individuals, families, and communities.

A central aspect of this reorganization is *districting*. Districting generally refers to the problem of dividing a set of so-called Territorial Units (TUs) into a predefined number of clusters or districts according to some planning criteria. The latter typically include: *integrity*, *balancing*, *contiguity*, and *compactness*. Integrity means that each TU belongs to only one district. Balancing expresses the need for districts of similar size w.r.t. some activity measures associated with the TUs (e.g., areas, population, demand for a service). Contiguity implies that the devised districting plan does not include enclaves, which also ensures that there is always a path connecting two TUs belonging to the same district that does not cross any other district. Finally, compactness is a topological property requiring that districts do not have elongated shapes. Other relevant criteria may apply depending on the specific application context. [7]
Districting Problems (DPs) have been successfully used to model and solve mid- to long-term strategic decision problems in various fields, such as service-oriented applications. Among the diverse service-oriented applications is health care. Home care, primary and secondary health care and emergency care are the three main areas where the underlying health care planning problem is seen and therefore addressed as districting problem. [8]
One of the most crucial aspects of health service planning - and the core issue arising from Italy's strategy - is the design of health service regions, i.e., the districting of health services. Building on these principles, this study focuses on the design of primary care service networks in Italy. Specifically, we refer to districting problem for the design and/or re-design of the districts (to be intended as the territorial branch of the LHA) and the catchment areas of the newly introduced CHCs. This is to ensure that the reform can effectively enhance the accessibility of these services for the population and ensure equity in care. [8]
To this end, the present study proposes ad-hoc districting models and uses real geographic data referring to multiple Italian regional case studies. The application allows to evaluate the potential social impacts of the ongoing reform under various strategies to operate CHCs.

Bibliography

[1] World Health Organization - Ageing and health https://www.who.int/news-room/fact-sheets/detail/ageing-and-health

[2] Lopreite, M., and Zhu, Z. The effects of ageing population on health expenditure and economic growth in China: a Bayesian-VAR approach. *Social Science & Medicine*, 265: 113513, 2020.

[3] Golz, C., Oulevey Bachmann, A., Defilippis, T. S., Kobleder, A., Peter, K. A., Schaffert, R., Schwarzenbach, X., Kampel, T., and Hahn, S. Preparing students to deal with the consequences of the workforce shortage among health professionals: a qualitative approach. *BMC Medical Education*, , 22(1), 756, 2022.

[4] European Commission - Health and long-term care https://reform-support.ec.europa.eu/what-we-do/health-and-long-term-care_en

[5] OECD - Primary healthcare https://www.oecd.org/en/topics/primary-healthcare.html

[6] Mauro, M. and Giancotti, M. The 2022 primary care reform in Italy: Improving continuity and reducing regional disparities? *Health Policy*, 135, 104862, 2023.

[7] Kalcsics, J. and Ríos-Mercado, R. Z. Districting problems *Location Science*, 705-743 (2019).

[8] Yanık, S. and Bozkaya, B. A review of districting problems in health care *Optimal Districting and Territory Design*, 31-55,(2020).

Designing resilient networks: A robust approach to the location-routing problem

Bruna Figueiredo [a,*], **Amaro de Sousa** [b], **Rui Borges Lopes** [a]

[a] CIDMA/DEGEIT, University of Aveiro, Aveiro, Portugal, bruna.figueiredo@ua.pt, rui.borges@ua.pt
[b] IT/DETI, University of Aveiro, Aveiro, Portugal, asou@ua.pt
[*] Presenting author.

Keywords: Location-routing, Mixed-integer linear programming, Resilience

Supply chain networks are increasingly vulnerable to unexpected disruptions, whether caused by natural disasters or human actions, which can significantly compromise their operational continuity. These disruptions can significantly reduce the efficiency of the network or render it inoperable for extended periods [1]. The Capacitated Location-Routing Problem (CLRP) is a widely studied approach in network design optimization, combining strategic decisions regarding facility location and efficient vehicle routing. However, traditional CLRP formulations generally overlook strategies for mitigating the impacts of disruptions. This study proposes a new formulation aimed at developing resilient networks capable of operating efficiently in steady state while maintaining robust performance during supply chain disruptions.

The Robust CLRP (RCLRP) was developed with the aim of minimizing the operating costs of a network that ensures operational continuity even when facilities are disrupted. The proposed model focuses on the location of the facilities and on defining their capacity utilization to ensure that the network can meet customer demand both in steady state and when one of the facilities becomes inoperative. Additionally, the RCLRP optimizes the reconfiguration of distribution routes originally designed for the steady state, ensuring that affected customers are efficiently reassigned to alternative operational facilities. The formulation also enables the quantification of the impacts of disruptions in each open facility, helping to prioritize the fortification and risk mitigation efforts. To validate the effectiveness of the model, computational experiments were carried out using instances adapted from the literature. The performance of the RCLRP was compared with that of the traditional CLRP, analyzing its ability to maintain operational stability and minimize cost impact in disruption scenarios.

Experimental results show that the RCLRP can outperform the traditional CLRP during disruption scenarios. It can generate more stable solutions, ensuring demand fulfillment even when a facility becomes inoperative. Although the RCLRP incurs a slightly higher initial cost under steady-state conditions, it offers greater consistency during disruptions, reducing cost impact and enhancing network resilience.

The proposed RCLRP formulation offers robust solutions for supply chain networks, potentially overcoming the limitations of conventional approaches. Given that logistics networks are increasingly vulnerable to disruptions, the application of robust models, such as the one presented in this study, may prove essential to ensure operational continuity. Future research could explore scenarios involving simultaneous facility disruptions and develop more efficient algorithms for large-scale problems, thus further improving the practical applicability of the approach.

Bibliography

[1] Scaparra, M. P. and Church, R. L. Location problems under disaster events. *In* Laporte, G., Nickel, S., and Saldanha-da-Gama, F. (Eds.), *Location Science*, 2nd ed., Cham: Springer, 2019, pp. 631–656.

Bi-objective Location of Temporary Logistics Hubs for Enhancing Post-Disaster Relief Operations

Serena Fugaro [a,*], **Antonino Sgalambro** [b]

[a] Institute for Applications of Calculus "Mauro Picone", National Research Council of Italy, Rome (Italy), s.fugaro@iac.cnr.it,
[b] Leeds University Business School, University of Leeds, Leeds (UK), a.sgalambro@leeds.ac.uk
[*] Presenting author.

Keywords: Dynamic Flows, Hub Location, Humanitarian Logistics

Introduction

In post-disaster relief operations, the role of humanitarian logistics in ensuring a timely and effective delivery of aid is paramount. In particular, *Temporary Logistics Hubs* are essential facilities for the deconsolidation, storage, consolidation, and shipment of relief supplies [3]. In this work, we propose a novel approach to address the hub-and-spoke network design problem associated with the location of temporary logistics hubs for humanitarian logistics in post-disaster environments.

Problem Description

To this aim we address a *Bi-Objective Capacitated Multiple Allocation Hub Location Problem with Splittable Demand*. The decisions to be made include:

- where to locate temporary logistics hubs that act as intermediate facilities between the emergency relief providers (e.g., donors, government warehouses) and the affected areas;
- the amount of flow that should traverse the available network links to ensure a timely supply for each relief material.

Two objectives are considered to assess the performance of the designed network: minimising the average arrival time of the flows and minimising the latest arrival time.
Indeed, whilst time is a crucial factor in post-disaster operations management, it has received limited attention in humanitarian logistics problems in terms of modelling tools explicitly employed to ensure its adequate representation. In order to bridge this gap, in this work we make use of *Dynamic Flows*, i.e. Flows over time [1].
Actually, these humanitarian logistics operations are characterised by an inherent uncertainty resulting from different levels of accuracy for the related parameters [2]. To represent this aspect, we adopt ad hoc modelling tools; we also propose algorithmic approaches to mitigate the uncertainty while providing valuable decision support in post-disaster relief operations.

Bibliography

[1] Ford Jr, LR and Fulkerson, DR Flows in Networks. *Princeton University Press,* 1962

[2] Jiang, J., Li, Q., Wu, L., and Tu, W. Multi-objective emergency material vehicle dispatching and routing under dynamic constraints in an earthquake disaster environment. *ISPRS International Journal of Geo-Information*, 6(5), 142, 2017.

[3] Maharjan, R., and Hanaoka, S. A credibility-based multi-objective temporary logistics hub location-allocation model for relief supply and distribution under uncertainty. *Socio-Economic Planning Sciences*, 70, 100727, 2020.

Tackling the discrete α-neighbor p-center problem with integer programming

Elisabeth Gaar [a,*], Markus Sinnl [b]

[a] University of Augsburg, Germany, elisabeth.gaar@uni-a.de
[b] Institute of Business Analytics and Technology Transformation/JKU Business School, Johannes Kepler University Linz, Austria, markus.sinnl@jku.at
[*] Presenting author.

Keywords: location science, p-center problem, integer programming formulation, min-max objective

The discrete α-*neighbor p-center problem* (α-pCP), introduced by Krumke [3], is a variation of the well-known discrete p-center problem (pCP, also referred to as the *vertex* pCP) that has gained attention in recent literature. Given a set of discrete points, the objective is to place p facilities at some of these points in a way that minimizes the maximum distance between any point without a facility and its α nearest facility.

The α-pCP can be interpreted as a more robust version of the pCP, where customers do not need to go to their closest facility, but also have additional $\alpha - 1$ facilities nearby. This characteristic makes the α-pCP particularly relevant for applications of the pCP where resilience is essential, such as the placement of emergency services or the coordination of humanitarian relief efforts.

Formally, the α-pCP is defined as follows: Given a set of points N, a positive integer p satisfying $p < |N|$, and a positive integer α such that $\alpha \leq p$, we are provided with a distance $d_{ij} \geq 0$ for all pairs of points $i, j \in N$. A feasible solution consists of selecting a subset $P \subseteq N$ with $|P| = p$ to serve as facility locations. The demand points are given by $N \setminus P$, meaning they depend on the chosen facility locations and include all points where no facility is placed. For a given feasible solution P, the α-distance $d_\alpha P, i$ for a demand point $i \in N \setminus P$ is defined as

$$d_\alpha P, i = \min_{A \subseteq P, |A| = \alpha} \max_{j \in A} d_{ij},$$

which represents the distance between i and its α closest facility in P. The objective function value $f_\alpha P$ for a given solution P is defined as

$$f_\alpha P = \max_{i \in N \setminus P} d_\alpha P, i,$$

and the α-pCP can be formulated as

$$\min_{P \subseteq N, |P| = p} f_\alpha P.$$

A special case of the problem corresponds to the classical pCP, which is obtained by setting

$\alpha = 1$ when assuming that $d_{ii} = 0$ for all $i \in N$. Up to now, research on the α-pCP has focused on approximation algorithms, such as those introduced by Krumke [3], and heuristic approaches developed by Mousavi [4] as well as Sánchez-Oro, López-Sánchez, Hernández-Díaz, and Duarte [5].

In this work, we propose exact solution methods for solving the α-pCP. We present two different integer programming formulations for the problem, along with valid inequalities, (iterative) lifting procedures for selected inequalities, and inequalities that preserve the optimal objective function value. Additionally, we introduce an (iterative) variable fixing technique. Our lifting procedures leverage lower bounds for the problem and extend existing results on the pCP by Gaar and Sinnl [2]. We demonstrate that applying the lifting and variable fixing procedures iteratively leads to convergence toward a specific fractional set cover solution. Furthermore, we establish that the optimal objective function value of a semi-relaxation of one of our formulations—where one set of binary variables remains binary while the other is relaxed—can be determined in polynomial time using iterative variable fixing. This result extends findings by Elloumi, Labbé, and Pochet [1] for the pCP and a fault-tolerant variant of the problem. Additionally, we conduct a polyhedral comparison of the formulations.

Building on these formulations and theoretical insights, we develop branch-and-cut (B&C) algorithms for solving the α-pCP. Our algorithms incorporate both an initial heuristic and a primal heuristic to enhance computational efficiency. We evaluate their performance using benchmark instances from the literature. Our results show that the proposed B&C algorithms successfully prove optimality for 116 out of 194 instances. Moreover, we improve the best-known solution values for 116 of these 194 instances. Importantly, these two subsets of 116 instances do not entirely overlap, as some optimal solutions had already been identified by existing heuristics, albeit without proof of optimality.

Bibliography

[1] Elloumi, S., Labbé, M., and Pochet, Y. A new formulation and resolution method for the p-center problem. *INFORMS Journal on Computing*, 16(1):84–94, 2004.

[2] Gaar, E. and Sinnl, M. A scaleable projection-based branch-and-cut algorithm for the p-center problem. *European Journal of Operational Research*, 303(1):78–98, 2022.

[3] Krumke, S.O. On a generalization of the p-center problem. *Information Processing Letters*, 56(2):67–71, 1995.

[4] Mousavi, S.R. Exploiting flat subspaces in local search for p-center problem and two fault-tolerant variants. *Computers & Operations Research*, 149:106023, 2023.

[5] Sánchez-Oro, J., López-Sánchez, A.D., Hernández-Díaz, A.G., and Duarte, A. GRASP with strategic oscillation for the α-neighbor p-center problem. *European Journal of Operational Research*, 303(1):143–158, 2022.

Upgrading on edges and facilities for the Multi-Type Maximal Covering Location Problem

Marta Baldomero-Naranjo [a], Ricardo Gázquez [b,*], Antonio M. Rodríguez-Chía [a]

[a] Universidad de Cádiz, Spain, marta.baldomero@uca.es, antonio.rodriguezchia@uca.es
[b] Universidad de Granada, Spain, rgazquez@ugr.es
[*] Presenting author

Keywords: Covering Problems, Upgrading, Maximal Covering Location Problems

This presentation focuses on the Maximal Covering Location Problem (MCLP), a well known problem in the area of covering location problems. The MCLP was introduced by authors in [4], and since its introduction it has gained the interest of the scientific community. This type of problem appears when facilities provide service up to a certain distance or a maximum time and we have a budget for the facilities that we must accommodate them in order to capture the maximum possible demand.
Although most of the literature is developed on problems using a single setting, mostly discrete location spaces, recently the use of different settings in the same problem with the name of Multi-type Maximal Covering Location Problem has been studied by authors in [2].
On the other hand, the upgrading extension of the location problems involve the coordination of facility location decisions with the enhancement of associated infrastructure. In the case of MCLP, we find upgrading when the network is upgraded and then the distance or time from a facility to a customer is reduced ([1]).
In this presentation we consider simultaneously the two approaches described above: different types of facilities, continuous and network settings, and two different types of upgrading, on the facilities and the network.
This new problem responds to real applications such as telecommunication networks. This is the case for telecommunication services in rural areas, where deploying a cable network is unfeasible due to the high costs associated with installing a traditional cellular network that relies on fixed Base Stations (BSs). One way to address this challenge is by using Unmanned Aerial Vehicle (UAV) based BSs to provide cellular coverage, supported by ground sites that connect the UAVs to the rest of the network (see e.g. [3]).
Beyond the study of this gap in the literature with important applications in the real-world, the contributions of this talk can be summarized as follows:

- A non-linear formulation with a Mixed Integer Second Order Cone (MISOCO) reformulation for it.
- For the Euclidean planar case we derive two full integer linear formulations.
- We propose a set of valid inequalities and study their validity for each of the reformulations, MISOCO and integer.
- We present significant findings from a comprehensive set of computational experiments.

Bibliography

[1] Baldomero-Naranjo, M., Kalcsics, J., Marín, A., and Rodríguez-Chía, A. M. Upgrading edges in the maximal covering location problem. *European Journal of Operational Research*, 303(1), 14–36, 2022.

[2] Blanco, V., Gázquez, R., and Saldanha-da-Gama, Francisco Multi-type maximal covering location problems: Hybridizing discrete and continuous problems. *European Journal of Operational Research*, 307(3), 1040–1054, 2023.

[3] Chiaraviglio, L., Amorosi, L., Blefari-Melazzi, N., Dell'Olmo, P., Lo Mastro, A., Natalino, C., and Monti, P. Minimum cost design of cellular networks in rural areas with UAVs, optical rings, solar panels, and batteries. *IEEE Transactions on Green Communications and Networking*, 3(4),901–918, 2019.

[4] Church, R. and ReVelle, C. The maximal covering location problem. *Papers in Regional Science*, 32(1), 101–118, 1974.

Probabilistic Cooperative Coverage Location Problems: a Robust Optimization Approach

Ioannis Giannikos *, **Maria Mihopoulou**

Department of Business Administration, University of Patras, Greece
i.giannikos@upatras.gr, mihopoulou@upatras.gr
* Presenting author.

Keywords: Cooperative Coverage, Robust Optimization

Abstract

This paper examines discrete cooperative coverage problems, where facilities work together to serve a set of demand points, each associated with a specific demand. Coverage is defined probabilistically to account for fluctuations caused by factors such as weather conditions, technical malfunctions, or other unpredictable variables. Additionally, we consider facilities of different types, distinguished by their costs and coverage capabilities, and assume that their operation is correlated to a varying degree.

We extend the models presented by [2], incorporating uncertainty in both the demand at demand points and the costs of facility location. Building on the approaches proposed by [1] and [3], we develop a robust optimization model aimed at maximizing demand coverage within a given budget. We compare different versions of the model and evaluate their performance through a series of computational experiments.

Bibliography

[1] Liu, H. and Song, G. Employing an Effective Robust Optimization Approach for Cooperative Covering Facility Location Problem Under Demand Uncertainty. *Axioms*, 11, 433, 2022.

[2] Michopoulou M. and Giannikos I. Discrete cooperative coverage location models with alternative facility types in a probabilistic setting. *International Transactions in Operational Research*, https://doi.org/10.1111/itor.13426, 2024.

[3] Usefi N., Seifbarghy M., Sarkar M., and Sarkar B. A Bi-Objective Robust Possibilistic Cooperative Gradual Maximal Covering Model for Relief Supply Chain with Uncertainty. *RAIRO*, 57, 761–786, 2023.

Competitive Location with NPV Maximization in a Discrete Setting: Comparing Sequential and Simultaneous Decisions

Pedro Godinho *

University of Coimbra, CeBER and Faculty of Economics, Portugal, pgodinho@fe.uc.pt
* Presenting author.

Keywords: Competitive location problems, Game theory, Location games

Introduction

I consider a setting based on [1, 2], in which two franchisees - the players - simultaneously choose locations for their facilities. The players have a budget constraint and there is a discrete, finite set of potential locations they may choose. While in [1, 2] the players want to choose the set of locations that maximize the demand, in this work I consider the more realistic objective of NPV maximization, taking into account the initial investment, revenues, fixed and variable costs.
The facilities will sell goods to clients. The clients are located in a discrete set of points and patronize the nearest facility. There is a franchiser that keeps a percentage of revenues and defines the rules of the game. So, the franchiser is interested in maximizing the present value of the total sales.
I consider sequential and simultaneous settings, and analyse the obtained equilibria from both the franchisees' and the franchiser's perspectives. In the sequential setting, the equilibrium is the solution of a bilevel problem with binary decision variables. The simultaneous problem is somewhat more complex, since the equilibrium may involve mixed strategies. For this case, I use an algorithm based on the one proposed in [1, 2].
I consider the problem with co-location and without co-location. In the case that co-location is not allowed, I consider that a player may have preference in choosing a potential location, when both are interested in opening a facility at the same spot.
In the case of the simultaneous game without co-location, one player may not be able to open facilities in all the potential locations in which he/she expresses interest. In that case, he/she may want want to express interest in more locations than he/she can afford (overbidding). In this case, the franchiser will define a penalty for each potential location that a player gets but where he/she is unable to open a facility.

Research Questions

I perform a simulation study, with randomly defined locations, and aim to answer the following questions:
- Is it preferable for the franchiser to define a simultaneous or a sequential setting?
- Is it preferable for the franchiser to allow co-location or not to allow it?
- What is the impact of budget asymmetries in the players and frachiser's payoffs?
- What is the impact of the number of potential locations in the players and frachiser's payoffs?

- Should the franchiser allow a player to have preference in choosing a potential location, when both are interested in opening a facility at the same spot?
- What penalty should the franchiser define for a player that is not able to open a facility in a potential location alloted to him/her?

Bibliography

[1] Godinho, P. and Dias, J. A Two-player Competitive Discrete Location Model with Simultaneous Decisions. *European Journal of Operational Research*, 207(3), 1419-1432, 2010.

[2] Godinho, P. and Dias, J. Two-Player Simultaneous Location Game: Preferential Rights and Overbidding. *European Journal of Operational Research*, 229(3), 663-672, 2013.

A Location-Routing Problem with Customers' Delivery Preferences

José Emmanuel Gómez-Rocha [a,*], José-Fernando Camacho-Vallejo [a], Elena Fernández [b]

[a] Tecnologico de Monterrey, Mexico, emmanuel.gr@tec.mx, fernando.camacho@tec.mx,
[b] Universidad de Cadiz, España, elena.fernandez@uca.es
[*] Presenting author.

Keywords: Location science, Routing, Customer preferences

Introduction

Integrated models involving facility location and routing decision have gained significance, particularly in strategic, tactical, and operational decision-making, where the primary focus has been cost minimization [4]. In recent years, these models have evolved to incorporate customer-oriented metrics, such as latency [2, 3] and customer satisfaction [5]. In last-mile delivery scenarios, it is common that customers prefer service models incorporating the flexibility to either wait and receive a package at their home locations within a given time window or, based on personal preferences, pick up their package from a selected pickup center.

Motivated by this situation, we address a problem in which a last-mile delivery company seeks to determine optimal delivery decisions while considering the customers' preferences for delivery times. If the delivery time offered to a customer deviates from his stated preference, the customer may choose to pick up his package from an open pickup center, incurring a penalty cost for the delivery company.

In this problem, a decision-maker from the delivery company must simultaneously determine i) a set of pickup centers to open (facility location decisions), ii) a service point for each customer (allocation decisions), and iii) a service route visiting all the activated pickup centers plus the service points of all the customers. The service points (pickup points) of the customers are determined based on their preferences and, for each customer, it will be either its home location or an activated pickup center. The company aims to minimize the investment and operational costs, plus the penalties due to order delays, with the latter serving as a metric for service level.

We introduce two location-routing models where the complexities due to the customers preferences are incorporated progressively. The first one only considers routing decisions based on customers' ideal delivery times, but involves no location decisions. We then extend this model to the problem under study, allowing the company to make location decisions and to allocate some customers to specific pickup centers. In both cases, mixed-integer linear programming formulations are proposed.

Before presenting numerical results for the proposed model, we detail some of its properties and, based on numerical studies, demonstrate the impact of different costs and parameters to derive managerial insights. Since larger instances become difficult to solve, we propose a matheuristic that leverages a surrogate model and a fix-and-optimize approach to address them efficiently.

Our choice of a matheuristic procedure is motivated by its strong performance across a wide range of combinatorial problems [1]. Furthermore, in practice, these procedures are often easier to adapt and maintain than pure metaheuristics, where incorporating new constraints can be challenging. Our results also highlight managerial benefits, and the matheuristic demonstrated strong performance compared to solving the formulation with a general-purpose solver.

Bibliography

[1] Fischetti, M. and Fischetti, M. Matheuristics. *Handbook of heuristics*, (pp. 121-153). Springer, 2018.

[2] Moshref-Javadi, M. and Lee, S. The latency location-routing problem *European Journal of Operational Research*, 255(2), 604-619, 2016.

[3] Nucamendi-Guillén, S., Gómez-Rocha, J. E., and Camacho-Vallejo, J.F. and Moraga Pardo, J. A., and González-Ramírez, Rosa G. The latency location routing problem with split deliveries: mathematical formulation and metaheuristic algorithm *International Transactions in Operational Research*, 2025.

[4] Prodhon, C. and Prins, C. A survey of recent research on location-routing problems *European Journal of Operational Research*, 238(1), 1-17, 2014.

[5] Wang, Y., Assogba, K., Liu, Y., Ma, X., Xu, M., and Wang, Y. Two-echelon location-routing optimization with time windows based on customer clustering. *Expert Systems with Applications,* 104, 244-260, 2018.

Extending the λ-Cent-Dian concept in Network Design Problems

Víctor Bucarey [a], Natividad González-Blanco [b,*], Martine Labbé [c], Juan A. Mesa [d]

[a] Universidad de O'Higgins, Institute of Engineering Sciences, Chile
victor.bucarey@uoh.cl,
[b] Universidad Loyola Andalucía, Departamento de Métodos Cuantitativos, Spain
ngonzalez@uloyola.es
[c] Université Libre de Bruxelles, Département d'Informatique, Belgium
mlabbe@ulb.ac.be
[d] Universidad de Sevilla, Departamento de Matemática Aplicada II, Spain
jmesa@us.es
* Presenting author.

Keywords: λ-Cent-Dian Problem, Generalized-Center Problem, Network Design

Introduction

In [1], the concept of λ-cent-dian was introduced for location problems where the goal is to minimize a linear combination of center and median objectives.
On one hand, the median problem is particularly useful in scenarios where the main focus is cost reduction or profit maximization within the system. On the other hand, the center problem is ideal for situations where the objective is to minimize the distance to the farthest point from the facility, such as when placing emergency services. However, when considered independently, these two objectives often fail to address real-world issues that require a balance between efficiency and fairness.
The generalized-center objective emphasizes fairness among origin/destination pairs, but as pointed out by [2], it can sometimes result in inefficient solutions.
The λ-cent-dian objective has also been applied in a variety of facility location problems. Examples of such facilities include paths, cycles, or trees in graphs, as well as straight lines, circles, and hyperplanes in Euclidean spaces (see [3], [4]).
In this work, we extend the concepts of λ-cent-dian and generalized-center from Facility Location Theory to the more complex field of Network Design. Our focus is on designing a sub-network within a given underlying network, subject to a budget constraint. The goal of this sub-network is to efficiently serve a set of origin/destination pairs of demand.
The λ-cent-dian problem examines the trade-off between efficiency and fairness. We explore the properties of the λ-cent-dian and generalized-center solution networks in terms of fairness, efficiency, and Pareto-optimality. Finally, we prove that the problems addressed in this paper are NP-hard.

Bibliography

[1] Halpern, J. The location of a center-median convex combination on an undirected tree. *Journal of Regional Science*, 16(2), 237-245, 1976.

[2] Ogryczak, W. On cent-dians of general networks. *Location Science*, 5(1), 15-28, 1997.

[3] O'Kelly, M. E. A review of extensive facility location in networks. *European Journal of Operational Research*, 95(3), 592-603, 1996.

[4] Puerto, J., Ricca, F., and Scozzari, Andrea. Extensive facility location problems on networks with equity measures. *Discrete Applied Mathematics*, 157(5), 1069-1085, 2009.

The Bounded Fixed-Charge Problem: A Compact and Tight Extended Formulation

Kobe Grobben *, **Hande Yaman** , **Phablo Moura**

Ku Leuven (ORSTAT), Kobe.grobben@kuleuven.be, Hande.Yaman@kuleuven.be, Phablo.Moura@kuleuven.be
* Presenting author.

Keywords: Union of Polyhedra, Tight Extended Formulation

Introduction

This study examines the bounded fixed-charge problem from a polyhedral perspective. This problem is a classical optimization problem commonly encountered in facility location planning. The goal of such a problem is to identify the optimal set of facilities to locate and determine the quantities to be delivered, ensuring demand at a central customer is met while minimizing fixed and variable costs. The problem is subject to constraints on the capacity of the facilities, the minimum delivery quantity of a facility and the demand to be met at the customer. Specifically, this study focuses on a variant where facilities differ only in terms of costs, with all facilities having identical capacities and minimum delivery requirements.

The polyhedral structure of this problem has been studied before. In [3], this problem is referred to as the single-item capacitated lot-sizing problem with lower bounds on production. In that paper, the convex hull description is provided only for the trivial case where the capacity of a single facility is at least as large as the demand of the central customer, implying no effective capacity constraint on production. This paper focuses on analyzing the more general polyhedron where a real capacity constraint may exist.

From the single-item lot-sizing literature, it becomes clear that the problem studied in this paper is easy and can be solved in polynomial time through dynamic programming (DP). [4] introduces a DP algorithm for the single-item capacitated lot-sizing problem with concave production and storage costs, achieving a time complexity of OT^6, where T represents the number of production periods. In the specific case of the bounded fixed-charge setting, the time complexity reduces significantly to On^2, where n represents the total number of facility locations. Despite the availability of efficient DP algorithms, exploring the convex hull of these problems remains valuable, as the goal of this polyhedral analysis is to utilize the compact and tight extended formulation to facilitate solving mixed-integer models in which this problem appears as a substructure. One notable application is in models that account for disruption scenarios.

Methodology

The methodology proposed in this paper is formulated through a series of structured steps. By leveraging an extended formulation similar to the one introduced in [5] for the single-item lot sizing problem, the problem is reformulated to align with the union of polyhedra described in [1] and [2]. By applying the union-of-polyhedra framework, the original problem is reduced to solving a polynomial number of two-coefficient 0-1 knapsack problems with a single bounded continuous variable. Repeating this approach, a second application of the union-of-polyhedra framework simplifies the problem further, reducing it to solving a polynomial number of one-coefficient 0-1 knapsack problems with a single bounded continuous variable. As it is possible to describe the convex hull of this last problem, the result is a tight extended formulation for the bounded fixed-charge problem. Moreover, this formulation is compact, as the number of added constraints and variables in the extended formulations, along with the number of problems to be solved after applying the union-of-polyhedra framework, is polynomial in nature. An important caveat is that the projected feasible region of the tight and compact extended formulation is a subset of the feasible region of the bounded fixed charge problem. However, when minimizing the total cost, which is the only objective used in practice, the projected feasible set of the extended formulation still includes all possible optimal solutions.

Although this study builds upon existing approaches, it makes several novel contributions to the literature. First, it applies methods from the lot-sizing literature to a related but distinct problem: the bounded fixed-charge problem. Second, it introduces techniques to effectively limit the size of the extended formulation, enhancing computational tractability. Finally, and most importantly, the paper develops a compact and tight extended formulation specifically tailored for the bounded fixed-charge problem, addressing a key gap in the literature.

Bibliography

[1] Balas, E. Disjunctive Programming and a Hierarchy of Relaxations for Discrete Optimization Problems. *SIAM Journal on Algebraic Discrete Methods*, 6(3), 466–486, 1985.

[2] Balas, E. Disjunctive programming: Properties of the convex hull of feasible points. *Discrete Applied Mathematics*, 89(1–3), 3–44, 1998.

[3] Constantino, M. Lower Bounds in Lot-Sizing Models: A Polyhedral Study. *Mathematics of Operations Research*, 23(1), 101–118, 1998.

[4] Hellion, B., Mangione, F., and Penz, B. A polynomial time algorithm to solve the single-item capacitated lot sizing problem with minimum order quantities and concave costs. *Operations research*, 222(1), 10–16, 2012.

[5] Park, Y. W. and Klabjan, D. Lot sizing with minimum order quantity. *Discrete Applied Mathematics*, 181, 235–254, 2015.

A capacitated facility location pricing problem with order

Herminia I. Calvete [a,b], Carmen Galé [a,b], Aitor Hernández [a,b,*], José A. Iranzo [a,b]

[a] Instituto Universitario de Investigación de Matemáticas y Aplicaciones (IUMA),
Universidad de Zaragoza,
Calle Pedro Cerbuna 12, 50009, Zaragoza, España.
[b] Departamento de Métodos Estadísticos,
Universidad de Zaragoza
Calle Pedro Cerbuna 12, 50009, Zaragoza, España.
[*] Presenting author.

Keywords: Capacitated facility location problem, Pricing decisions, Bilevel optimization

Facility location analysis has a wide range of applications in both the public and private sectors, thus playing a crucial role in decision-making processes. The main purpose of facility location problems is to determine the optimal placement of a set of facilities to meet the needs of the system under study. There exist in the literature a large number of variants of the facility location problem, as it allows for incorporating a broad variety of specific characteristics in the optimization process, such as customer preferences or pricing, among others. Hanjoul *et al.* [4] were the first to introduce customer preferences into facility location problems. They extend the so-called *Simple Plant Location Problem* (SPLP) by incorporating a specific set of constraints which ensures that customers are assigned to their most preferred facility. They name this new problem the *Simple Plant Location Problem with Order* (SPLPO). Although the inherent hierarchical structure is already recognized in [4], it is not until years later that Hansen *et al.* [5] focus on this bilevel structure and study the problem formulated as a pure binary bilevel optimization model. Calvete *et al.* [2] extend the SPLPO by adding capacity constraints. They propose two formulations for the problem: a single level formulation and a bilevel formulation, the latter solved by means of a matheuristic algorithm considering an utilitarian approach. On the other hand, Hanjoul *et al.* [3] discuss the role of pricing policies in facility location decisions. They define two pricing policies: the mill pricing policy, which corresponds to the cases where customers are responsible for the assignment or travel costs, and the delivered pricing policy, which corresponds to the cases where the assignment costs are assumed by the location decision maker. Finally, Calvete *et al.* [1] combine customer preferences and a mill pricing policy in a facility location problem for the first time. They formulate a mixed integer bilevel optimization model and reformulate it as a mixed integer single level optimization model, which is efficiently solved by off-the-shelf optimization software. Building upon this previous research, we now extend the problems studied in the literature integrating customer preferences, capacity constraints, and a delivered pricing policy into the same facility location problem. We formulate a bilevel optimization model for the problem, which can be solved exactly by reformulating it as a single level model. A computational study is conducted to analyze the performance of the exact solution method, allowing us to present some preliminary results. Table 4 summarizes the key contributions made in the literature and compares them with the approach presented in this study.

Table 4: Overview of the literature on facility location problems, indicating which studies consider capacity constraints, customer preferences, pricing decisions, and bilevel structures.

Reference	Capacity	Preferences	Pricing	Bilevel
Hanjoul *et al.* [4]	–	✓	–	–
Hanjoul *et al.* [3]	–	–	✓	–
Calvete *et al.* [2]	✓	✓	–	✓
Calvete *et al.* [1]	–	✓	✓	✓
This study	✓	✓	✓	✓

Bibliography

[1] Calvete, H. I., Galé, C., Hernández, A., and Iranzo, J. A. A bilevel approach to the facility location problem with customer preferences under a mill pricing policy. *Mathematics*, 12, 3459, 2024. DOI: https://doi.org/10.3390/math12223459

[2] Calvete, H. I., Galé, C., Iranzo, J. A., Camacho-Vallejo, J. F., and Casas-Ramírez, M. S. A matheuristic for solving the bilevel approach of the facility location problem with cardinality constraints and preferences. *Computers and Operations Research*, 124, 105066, 2020. DOI: https://doi.org/10.1016/j.cor.2020.105066

[3] Hanjoul, P., Hansen, P., Peeters, D., and Thisse, J. F. Uncapacitated plant location under alternative spatial price policies. *Management Science*, 36(1), 41–57, 1990. DOI: https://doi.org/10.1016/0166-0462(87)90011-1

[4] Hanjoul, P. and Peeters, D. A facility location problem with clients' preference orderings. *Regional Science and Urban Economics*, 17, 451–473, 1987. DOI: https://doi.org/10.1016/0166-0462(87)90011-1

[5] Hansen, P., Kochetov, Y. A., and Mladenović, N. Lower bounds for the uncapacitated facility location problem with user preferences. In *Proceedings of 2nd International Workshop Discrete Optimization Methods in Production and Logistics*, 50–55, 2004.

A Deterministic Utility Model for the Leader-Follower Competitive Facility Location Problem with Facility Attractiveness

Julius Hoffmann [a,*], **Stefan Nickel** [a]

[a] Institute for Operations Research, Karlsruhe Institute of Technology, julius.hoffmann@kit.edu, stefan.nickel@kit.edu

[*] Presenting author.

Keywords: Competitive Facility Location, Leader-Follower Game, Deterministic Utility Model

The competitive facility location problem (CompFLP) has become an integral part of location theory literature and combines this research area with game theory. In the mentioned problem family, two or more companies compete for the demand of given customers by determining the locations and possibly other properties of their facilities.

Many variants of the CompFLP have been studied. One crucial aspect of the problem setting is the chronology of the moves of the competitors. In our work, we study a Leader-Follower (Stackelberg) model where a leader must perform the first move in anticipation of the response of the follower. Another important part of the problem definition are the criteria according to which the customer demand is assigned to the players. For example, the demand of a single customer can be assigned completely to one of the competitors (deterministic utility model) or can be split between the competitors according to attractiveness criteria of the facilities and personal preferences (random utility models). While it is possible in most of the random utility models to attract more customer demand by enhancing the attractiveness of the facilities via investments, we are not aware of this problem configuration for deterministic utility models with the Leader-Follower setting.

We address this research gap in our work and consider the Leader-Follower CompFLP in a deterministic utility framework and with facility expansion possibilities (LF-CompFLP-DU-FE). For this problem, we present a mathematical model via bilevel programming. Additionally, we show some important problem properties and appropriate computational methods for solving the problem configuration.

Integrating E-Scooters into Urban Mobility: Coupled Location Problems for Seamless Multimodal Transport

Nicolas Fröhlich [a], **Klara Hoffmann** [a,*], **Anita Schöbel** [a,b]

[a] Fraunhofer ITWM Kaiserslautern, Germany
[b] RPTU Kaiserslautern, Germany
nicolas.froehlich@itwm.fraunhofer.de
klara.hoffmann@itwm.fraunhofer.de,
anita.schoebel@itwm.fraunhofer.de,
[*] Presenting author.

Keywords: Mobility, E-scooter, Public Transport, Travel Time, Covering

Abstract

E-scooters and shared bikes have become a common supplementary mode of transportation in cities allowing travelers to efficiently travel short distances. They are also often used to access train stations or bus stops. While shared bikes are usually found at special bike stations, there are often no dedicated parking zones for e-scooters. This may cause problems for pedestrians if scooters block public space. Many cities therefore contemplate designated parking areas for e-scooters to enhance urban aesthetics, improve pedestrian and cyclist safety, and promote sustainable transportation [4]. However, locating such parking areas should be in line with the locations of shared bikes, bus stops, train stations, or even car-sharing lots.

In this study we model the location of these different stations as a set of *coupled location problems*.

We first compare and extend known models (see, e.g., [1]) for optimizing the placement of e-scooter stations within a city. The proposed models aim to minimize construction costs while ensuring that all demand points are adequately covered within a specified radius. We explore variations of the covering problem, including fixed or variable station sizes and costs. Furthermore, we examine a covering variant with multiple covering radii depending on the size of the station built, which ultimately depends on the demand. To support urban planners in weighing the various objectives, we analyze a bi-criteria version of the problem that minimizes construction costs while maximizing covered demand. Moreover, we compare the covering approach with the median and center problem approaches. We also examine the interplay between the discrete and the continuous version of the location problem.

In a further step, we consider the location of parking areas for scooters together with the location of stations for other transport modes. I.e., we expand the e-scooter stations in a modular way by adding models for locating car- and bike-sharing stations. Bus stops and train stations are also important since travelers often use scooters or shared bikes to reach these stops or stations. We either consider given bus stops or use known models, e.g., as in [2,

5, 3] for finding stop locations. These different location models are then coupled to allow travelers to smoothly transfer from one mode to another.

The resulting formulation integrates the location of stations for different modes of transport and consists of several coupled location problems. As before, we follow different objectives: passengers should have good access to their nearest mobility station, additionally their traveling times should be considered. Another objective is to minimize costs to stay within a given budget. We study properties of such a coupling under various objective functions, discuss conflicts that may arise, and present some first results within the city of Kaiserslautern.

Bibliography

[1] Laporte, G., Nickel, S., and Saldanha da Gama, F. Location Science. *Springer International Publishing AG*, 2nd ed., 2020.

[2] Murray, A. A Coverage Model for Improving Public Transit System Accessibility and Expanding Access. *Annals of Operations Research* 123, pp. 143-156, 2003.

[3] Poetranto, D., Hamacher, H.W., Horn, S., and Schöbel, A. Stop Location Design in Public Transportation Networks: Covering and Accessibility Objectives. *TOP* 17(2), pp. 335-346, 2009.

[4] Rothhaar, A. Conceptions for e-scooter parking areas using the example of the city of Kaiserslautern. *Master Thesis at RPTU*, 2023.

[5] Schöbel, A. Optimization in public transportation. Stop location, delay management and tariff planning from a customer-oriented point of view. *Optimization and Its Applications, Springer, New York*, 2006.

Stable formulations for the Capacitated Facility Location Problem with Customer Preferences

Concepción Domínguez , Juan de Dios Jaime Alcántara *
University of Murcia, concepcion.dominguez@um.es, jd.jaimealcantara@um.es
* Presenting author.

Keywords: Location with preferences, Simple Plant Location Problem, Capacitated Facility Location, Combinatorial Optimization, Matchings under preferences

Introduction

The Capacitated Facility Location Problem with Customer Preferences (CFLCP) extends the classical Simple Plant Location Problem (SPLP) by incorporating customer choices into the allocation process. Traditionally, in facility location models, customers are assigned to open facilities based solely on cost minimization. However, in many real-world applications, customers have preferences over which facility they would like to be assigned to, adding an additional layer of complexity to the decision-making process.

In the CFLCP, each facility has a fixed capacity, meaning it can only serve a limited number of customers. Customers rank the available facilities according to their preferences, but due to capacity constraints, not all customers can be assigned to their most preferred option. This creates potential conflicts in the allocation, as some customers may prefer to be assigned to facilities that are already full, leading to situations of envy and instability in the solution.

To address this issue, we introduce different stability concepts inspired by matching problems under preferences [1]. Unlike traditional formulations that use numerical preference values to model customer choices, our approach considers only strict ordinal rankings of facilities by each customer. Given that not all customers can be assigned to their first-choice facility, we explore several decision rules to fairly distribute customers across facilities while maintaining stability in the allocation.

Bibliography

[1] Manlove, D. Algorithmics of matching under preferences (Vol. 2). *World Scientific*.

Locating Sorting Modules in a Multi-Hub E-Commerce Logistics Network

Zeynep Ezgi Kurban [a,*], **Bahar Yetiş Kara** [a,b], **Oya Karaşan** [b]
[a] Bilkent University, Turkey, ezgi.kurban@bilkent.edu.tr, bkara@bilkent.edu.tr,
[b] Bilkent University, Turkey, karasan@bilkent.edu.tr
[*] Presenting author.

Keywords: E-Commerce Logistics, Logistics Optimization, Network Flow, Hub Location Problem, Sorting Operations, Mixed-Integer Programming, Capacity Planning.

Introduction

E-commerce logistics networks rely on efficient sorting operations to ensure timely and cost-effective deliveries. This study presents an optimization model developed for a leading e-commerce company in Turkey, where commodities are transported via hubs and cross-docks. Shipments are processed through sorting modules, where workers classify packages based on their destination.

The network features two key sorting stages: pre-sorting, which groups shipments according to their final hub, and fine-sorting, which organizes shipments by their destination cross-dock. Each shipment—categorized as either oversized or parcel—undergoes pre-sorting at its origin hub. Fine-sorting may occur at intermediate hubs or the final hub before reaching its assigned cross-dock.

Problem Formulation

Each hub is equipped with pre-sorting and fine-sorting modules, both of which have limited capacity. The total processing time at a hub depends not only on sorting operations but also on volume-dependent loading and unloading times. The primary objective of this study is to determine the number of sorting modules per hub, minimizing processing delays while efficiently distributing fine-sorting tasks across the network.

Methodology

We formulate the problem as a mixed-integer programming (MIP) model, integrating network flow optimization and capacity planning. The objective function aims to minimize total processing time while satisfying demand and capacity constraints. The problem extends traditional hub location problems and multi-commodity flow models by incorporating sorting operations and hub congestion dynamics. A unique aspect of our approach is the inclusion of module capacity design, which directly influences processing times and overall network performance. This facet introduces a new perspective to optimization models in the literature by explicitly integrating sorting module capacity into the network design, leading to more realistic and scalable solutions.

Conclusion

Our findings provide valuable insights for strategic hub capacity planning in e-commerce logistics. The proposed optimization model enables more efficient operations, reduced transit delays, and scalable network design. By optimizing sorting module placement and capacity allocation, we achieve improved processing times, shorter delivery durations, and enhanced handling efficiency at hubs.

Linear constraints for describing spanning trees representing complete linkage dendrograms

Martine Labbé [a], Mercedes Landete [b,*], Marina Leal [b], Lorena Nácher [b]

[a] Computer Science Department, Université Libre de Bruxelles, Belgium, Martine.Labbe@ulb.be,

[b] Centro de Investigación Operativa, Universidad Miguel Hernández, Spain. landete@umh.es, m.leal@umh.es, lnacher@umh.es

[*] Presenting author.

Keywords: spanning tree, complete-linkage.

Abstract

Minimum spanning trees are present in many transportation networks. Sometimes the locations of services are decided taking into account that in addition to minimizing the total or the maximum distance of the distribution network, these service points are connected by a minimum spanning tree. These service points or facilities can be directly factories or hubs that allow for the distribution of demand flows. In this work, we raise the interest of using other spanning trees than the minimum distance. We propose the interest of using the spanning tree that corresponds to a complete-linkage dendrogram.

Dendrograms are graphical representations of hierarchical clustering. Different definitions of the distance between two groups in the hierarchical clustering lead to different dendrograms. In this paper we focus on the so-called "complete-linkage" dendrograms, which we obtain when this distance is assumed to be the maximum of the distances between the elements of both groups. From the point of view of graph theory, dendrograms are spanning trees with different properties. Dendrograms of the "single-linkage" type correspond to minimum-cost spanning trees, while the others correspond to trees that are not minimum-cost.

In this work, we propose a system of linear inequalities whose set of solutions is the complete set of "complete-linkage" dendrograms. This system of inequalities has two advantages. On the one hand, it allows us to choose a complete-linkage spanning tree as a transport network between the service points and on the other hand, it allows us to choose from all the complete-linkage spanning trees the one that is the best in terms of our objective.

Uniform partitioning problems and k-dimensional assignment

Isabella Lari [a,*], Federica Ricca [a], Andrea Scozzari [b]
[a] University of Rome La Sapienza, Italy
isabella.lari@uniroma1.it, federica.ricca@uniroma1.it,
[b] University Niccolò Cusano - Roma, Italy,
andrea.scozzari@unicusano.it
[*] Presenting author.

Keywords: Uniform k partitioning problems, range-based objective functions, k-dimensional assignment problems, matrix permutation.

Introduction

In this paper we study a class of *balanced* or *uniform* partitioning problems which consists of partitioning k sets, each with a cardinality of n, into n sets (or clusters) of cardinality k. Each cluster must contain exactly one element from every original set, while optimizing a measure of *uniformity* among the n sets. Assuming that a cost function is defined for each cluster, various uniformity criteria can be considered. We adopt a criterion based on the *range* of a cluster, i.e., the difference between the maximum and minimum "cost" of the elements in a cluster (see, also, [1, 3, 5, 6]). The goal is to find a partition of the k sets into n clusters of cardinality k that minimizes or maximizes a function of the clusters' range. We refer to these problems as *Range Uniform Partitioning problems* (RUP).

RUP problems belong to the class of *balanced optimization problems*, which have received significant attention in the literature since the seminal paper [7]. That paper introduced a framework encompassing many balanced optimization problems and presented polynomial-time algorithms to solve them. These problems cover a wide range of research areas, including the balanced version of the spanning tree problem [2] and the traveling salesman problem [8]. More recently, Range Uniform graph partitioning problems were introduced in [6]. Problems closely related to our RUP formulation were studied in [5], where different uniformity criteria were explored. Polynomial-time algorithms were provided for most cases, while a few were proved to be NP-hard.

Depending on the objective functions considered and the method used to compute the cost of a cluster, we define different new problems. In the first formulation, given a complete k-partite graph $G = V_1, \dots, V_k; E$ with $|V_i| = n$ for all $i = 1, \dots, k$ and weights assigned to the edges, we define the weight of a k-clique by its range, i.e., the maximum absolute difference between the weights of two edges whose endpoints belong to the k-clique. We then consider the problem of partitioning the graph into k-cliques in such a way that minimizes the maximum difference among the ranges of the k-cliques. We prove that this problem is NP-complete for $k = 3$. For $k = 2$, the problem is not defined, since a 2-clique does not contain two edges, which is the minimum required number to compute a difference. The case with arbitrary k and $n = 2$ remains an open question, though it appears to be a difficult problem as well.

For this problem we establish a close connection to the classical k-dimensional assignment problem (KDA) formulated in graph-theoretic terms [4]. In particular, for $k = 3$ the problem becomes partitioning a complete tripartite graph into triangles while minimizing a given cost function computed over the triangles. The RUP problem for $k = 3$ can be interpreted as a 3DA problem with a novel range-based objective function. If instead we consider the same problem with weights assigned to the vertices of the k-partite graph, and define the weight of a k-clique as the maximum difference between the weights of its two vertices, we obtain a special case of the previous problem. As pointed out in [5], for this version, the complexity of the general case is unknown. However, we have solved it with polynomial-time algorithms for $k = 2$ when n vertices belong to each side of the 2-partite graph, as well as for the case where k is arbitrary with two vertices in each V_i, $i = 1, \dots, k$, of the k-partite graph.
For the vertex-weighted complete k-partite graph model, we introduce new problems and, for $k > 3$, we present polynomial-time solution methods by leveraging the results in [5]. Finally, we extend the known complexity status of 3DA by incorporating additional decomposable cost functions based on the range criterion. Uniform partitioning problems studied in this paper feature the characteristics of some practical problems that arise in electoral systems.

Acknowledgments

The authors acknowledge the financial support received from the grant: Progetti di Ricerca di Rilevante Interesse Nazionale-PRIN Bando 2022 PNRR (Prot. P2022NK39A), Representation and Parliament Formation in democratic countries: fair procedures for equal and informed citizens (CUP F53D23009460001), funded by Unione Europea - Next Generation EU.

Bibliography

[1] Bruglieri, Maurizio, Cordone, Roberto, Lari, Isabella, Ricca, Federica, Scozzari, Andrea. On finding connected balanced partitions of trees. *Discrete Applied Mathematics*, 299, 1-16, 2021.

[2] Camerini, Paolo M., Maffioli, Federico, Martello, Silvano, Toth, Paolo. Most and least uniform spanning trees. *Discrete Applied Mathematics*, 15, 181-197, 1986.

[3] Cordone, Roberto, Franchi, Davide, Scozzari, Andrea. Cardinality constrained connected balanced partitions of trees under different criteria. *Discrete Optimization*, 46, 100742, 2022.

[4] Crama, Yves, Spieksma, Frits C.R. Approximation algorithms for three-dimensional assignment problems with triangle inequalities. *European Journal of Operational Research*, 60, 273-279, 1992.

[5] Dell'Olmo, Paolo, Hansen, Pierre, Pallottino, Stefano, Storchi, Giovanni. On uniform k-partition problems. *Discrete applied mathematics*, 150, 121-139, 2005.

[6] Hochbaum, Dorit S. Algorithms and complexity of range clustering. *Networks*, 73, 170-186, 2019.

[7] Martello, Silvano, Pulleyblank, William R., Toth, Paolo, De Werra, Dominique. Balanced optimization problems. *Operations Research Letters*, 3, 275-278, 1984.

[8] Vo, Thi Quynh Trang, Baiou, Mourad, Nguyen, Viet Hung. A branch-and-cut algorithm for the balanced traveling salesman problem. *Journal of Combinatorial Optimization*, 47, 1-22, 2024.

A stochastic hub location and protection problem

Armin Lüer-Villagra [a,*], **Gonzalo Méndez-Vogel** [a], **Vladimir Marianov** [b]

[a] Department of Engineering Sciences, Universidad Andres Bello, Autopista Concepción-Talcahuano 7100, Talcahuano, Chile, armin.luer@unab.cl, gonzalo.mendez@unab.cl
[b] Instituto Sistemas Complejos de Ingeniería (ISCI) and Department of Electrical Engineering, Pontificia Universidad Católica de Chile, Santiago, Chile, marianov@uc.cl
[*] Presenting author.

Keywords: Hub location, Interdiction models

Introduction

The design of resilient hub-and-spoke networks has been explored in the literature, mainly through reliability consideration [9, 1, 5, 2], and interdiction models, like [4, 6, 7, 8], among others. In most cases, both the attack and defense strategies are deterministic and known by both the attacker and the defender. Only a few works have considered interdictions of unknown size, such as [10] for a multi-commodity network design problem.

The problem

We study the problem faced by a company that aims to design a hub-and-spoke network that can be subject to one or more potential threats to the network operation. The company must determine the locations of its p hubs and protect q of them, all while considering potential threats to the operation of the network.

The company faces one or more attackers whose actions could potentially degrade network operation in an environment of uncertainty. It does not possess knowledge of the actual attack strategy, but has prepared several attack scenarios. In each scenario $s \in S$, the attackers interdict at most s hubs of the company's network.

The company's objective function is to minimize the pre-interdiction routing costs plus the expected demand disruption costs. In contrast, the attacker aims to maximize the expected demand disruption costs.

Solution methodology

We use the methodology proposed in [3] plus some variable fixing tests and the natural decomposition of the lower-level problem by scenarios to accelerate the solution procedure. We implemented the procedures using the CPLEX 22.1.1 API.

Preliminary results

We have found that acceleration techniques are effective, providing optimal or close to optimal solutions in reasonable computational times.

Bibliography

[1] Azizi, N., and Salhi, S. Reliable hub-and-spoke systems with multiple capacity levels and flow dependent discount factor. *European Journal of Operational Research*, 298, 834-854, 2022.

[2] Blanco, V., Fernández, E., and Hinojosa, Y. Hub Location with Protection Under Interhub Link Failures. *INFORMS Journal on Computing*, 35(5), 966-985, 2023.

[3] Fischetti, M., Ljubić, I., Monaci, M., and Sinnl, M. A New General-Purpose Algorithm for Mixed-Integer Bilevel Linear Programs. *Operations Research*, 65(6), 1615-1637, 2017.

[4] Ghaffarinasab, N. and Motallebzadeh, A. Hub interdiction problem variants: Models and metaheuristic solution algorithms. *European Journal of Operational Research*, 267, 496-512, 2018.

[5] Mohammadi, M., Jula, P., and Tavakkoli-Moghaddam, R. Reliable single-allocation hub location problem with disruptions. *Transportation Research Part E*, 123, 90-120, 2019.

[6] Quadros, H., Roboredo, M. C., and Pessoa, A. A. A branch-and-cut algorithm for the multiple allocation r-hub interdiction median problem with fortification. *Expert Systems With Applications*, 110, 311-322, 2018.

[7] Ramamoorthy, P., Jayaswal, S., Sinha, A., and Vidyarthi, N. Multiple allocation hub interdiction and protection problems: Model formulations and solution approaches. *European Journal of Operational Research*, 270, 230-245, 2018.

[8] Ramamoorthy, P., Jayaswal, S., Sinha, A., and Vidyarthi, N. An exact method for trilevel hub location problem with interdiction. *European Journal of Operational Research*, 319, 696-710, 2024.

[9] Rostami, B., Kämmerling, N., Buchheim, C., and Clausen, U. Reliable single allocation hub location problem under hub breakdowns. *Computers and Operations Research*, 96, 15-29, 2018.

[10] Vaziri, S. M., Kuzgunkaya, O., and Vidyarthi, N. An Exact Algorithm for Multicommodity Network Design Under Stochastic Interdictions. *INFORMS Journal on Computing*, Ahead of Print, 2025.

Competitive bi-level facility location with levels of service and stochastic customers preferences

Simona Mancini [a]*, Leandro C. Coelho [b]

[a] University of Palermo, Italy simona.mancini@unipa.it
[b] Universitè Laval, Quebec City, Canada Leandro.Callegari-Coelho@fsa.ulaval.ca
* Presenting author.

Keywords: Bi-level, Stochastic Optimization, Competitive facility location

Introduction

Facility location problems often rely on the assumption of monopoly, where the facilities owner offers a unique service (or product) and is the only player in the market. Most of location problems in the reality do not fit with this setting and need more complex models incorporating competition with other players. ([1]). Competitive facility location deals with locating new facilities in an environment where other facilities are already operating, with which the new facilities must compete to share the market. Another relevant aspect is that customers are not assigned to a specific facility but autonomously choose the facility to use according to their personal rationale. This is common in many real application, such as gyms, supermarkets and swimming pools location, just to name a few. When the type of service/product offered by the different competitors is the same, the rationale according to which the customers choose is very simple and rely on spatial distance or on accessibility level of the facility. Conversely, when facilities offer different level of services, the rationale becomes more complex, since it is based on both the quality of service and on the distance, but the weight the two criteria have on the final decision is generally unknown and may strongly differ from one individual to another. In this work we introduce the Competitive Bi-Level Facility Location with Levels of Service and Stochastic Customers Preferences (CBLFL-SCP), in which we optimize location and design (in terms of service level) of a set of facilities, under a given budget, in order to maximize the number of customers attracted by the new facilities, over a set of customers preference scenarios. The attractiveness of a facility is a linear combination of its distance from the customer and the service level offered, with stochastic coefficients.

Problem Description

We consider a set of customers I located in an area where a set of competitor facilities, F^C, is already operating. A budget B is available to open new facilities on a set of potential available locations F^O. We identify with J the total set of facilities (new and existing). The service level of a new facility is a decision variable itself, while that of a competitor facility is known and is indicated as q_j. A set of K levels is available, at each location j, each one associated with an opening cost b_{jk} and a service score l_k. The distance between each customer i and facility j is known and referred as d_{ij}. A set of customers preference scenarios, S, is given in input. For each scenario we know the importance a customer i gives, in the facility selection process, to the distance criteria, α_i^s, as a number included in the interval $0;1$. The importance of the service level criteria, β_i^S is computed as $1-\alpha_i^s$. We assume that customers can be attracted only by facilities located within a compatibility radius, ρ_k which depends on the service level offered by the facility. The parameter p_{ij}^s allows to compute the attractiveness of a facility j with respect to a customer i on scenario s. We define d^{MAX} and l^{MAX} as the maximum distance between a customer and a facility and the maximum service level score, respectively.

The goal is to maximize the number of customers attracted by the new facilities over all the scenarios. The decision variables involved in the model are the following. Variables y_{jk} indicate whether a facility of level k is opened at location j. These are first stage variables and the only set of variables on which the decision maker directly acts. Basing on the facility opening and design decisions the value of the attraction variables, x_{ij}^s, which indicate whether customer i is attracted by facility j on scenario s, is computed basing on the fact that each customer follows its rationale and is attracted by the facility with the highest score among those located within its compatibility radius. The goal is to maximize the number of attracted customers over all the scenarios (i.e. $\sum_s \sum_i \sum_{j \in F^O} x_{ij}^s$). The resulting problem can be classified as a two-stage stochastic bi-level problem with multiple followers.

Solution Approach

To efficiently and effectively solve the bi-level stochastic problem we propose a three-step deterministic policy, named POLU. The first step consists into solving a pessimistic (P) version of the model in which the goal is to maximize the number of customers attracted by a facility for any rate of importance of the distance/service level. This is equivalent to solve a robust version of the model. At the second step we solve an optimistic version of the problem (O), in which we use the residual budget (if any) to open additional facilities in order to maximize the number of customers that can be attracted for at least one value of α. At the third step, if there is still a residual budget available, we use it to upgrade the service in the facilities opened at the previous steps, in order to maximize the total service level score. This procedure is named as Level Upgrade (LU). Preliminary results show that the proposed policy outperforms the deterministic equivalent problem (DEP) (in which each uncertain parameter takes its expected value, i.e. where all the α takes value 0.5) and the pure optimistic and pessimistic policies.

Bibliography

[1] Plastria, F. Static competitive facility location: An overview of optimisation approaches *European Journal of Operational Research*, 129, 461-470, 2001.

An alternative Integer Programming formulation for the Linear Ordering Problem

Alfredo Marín [a*], Justo Puerto [b]

[a] Universidad de Murcia, Spain, amarin@um.es
[b] Universidad de Sevilla, Spain, puerto@us.es
[*] Presenting author.

Keywords: Linear ordering problem, discrete optimization, discrete location

The Linear Ordering Problem (LOP) is a classic combinatorial optimization problem with applications in economics (input-output analysis), logistics (rank aggregation), and social choice theory (voting systems). In this presentation, we introduce an alternative integer programming formulation for the LOP based on assignment variables and novel constraints. Unlike traditional formulations that rely on tournament variables (e.g., [3]), our approach leverages assignment-based modeling to enhance computational efficiency and flexibility. We discuss the theoretical foundations of the formulation, its advantages in terms of constraint structure, and preliminary computational results comparing it to existing methods.
The LOP is known to be equivalent to several other optimization problems, including

- The Triangular Feedback Arc Set Problem [4],
- The Slater Ranking Problem [5],
- The Minimum Violation Ranking Problem [1],
- The Rank Aggregation Problem [2]

This work contributes to the broader field of location science by providing a new perspective on solving ranking and seriation problems.

Bibliography

[1] Cohen, A.C. and Mallows, C.L. Assessing goodness of fit of ranking models. *Journal of the Royal Statistical Society: Series B*, 45(1), 54-62, 1983.

[2] Dwork, C., Kumar, R., Naor, M. and Sivakumar, D. Rank aggregation methods for the web. *Proceedings of the 10th international conference on World Wide Web* 2001.

[3] Grötschel, M., Jünger, M. and Reinelt, G. Facets of the linear ordering polytope. *Mathematical Programming*, 33(1), 43-60., 1985.

[4] Karp, R.M. Reducibility among combinatorial problems *In Complexity of Computer Computations* (pp. 85-103), 1972.

[5] Slater, P. Inconsistencies in a schedule of paired comparisons. *Biometrics*, 17(2), 215-220, 1961.

Study of parameter perturbations in the uncapacitated p-hub median location problem with Machine Learning

Inigo Martin Melero [a,*], **Mercedes Landete Ruiz** [a], **Vanesa Guerrero** [b]

[a] Universidad Miguel Hernandez de Elche, inigo.martin@goumh.umh.es, landete@umh.es,
[b] Universidad Carlos III de Madrid, vanesa.guerrero@uc3m.es
[*] Presenting author.

Keywords: P-Hub Median Location, Machine Learning, Heuristics

Abstract

In location science, hub location problems are used to connect demands in a network via hubs [1]. They are applied in a wide range of cases, like transportation and logistics, airlines and airports, postal delivery services, supply chains, telecommunications, and emergency services [2]. In some of these situations, variations in client demand flows within the network might occur and potentially alter the optimal distribution of hubs. Depending on the size of the hub location problem, updating the optimal solution in response to these demand changes might be straightforward or infeasible within a reasonable time.
A recent research trend explores the application of Machine Learning (ML) in Combinatorial Optimization to improve and speed-up decision-making [3]. Some authors [4] have applied ML techniques to manage small perturbations in certain location problems and predict potential changes in their optimal solution. Building on this idea, our work aims to use ML to address perturbations in client flows for the Uncapacitated Single-Allocation p-Hub Median Problem (UMApHMP), to predict the impact on the solution. We are interested in inter-hub complete and uncomplete networks and both small and large problems.

Bibliography

[1] Contreras, I. and O'Kelly, M. Hub location problems. *Location Science*, 327-363, 2019.

[2] Laporte, G., Nickel, S., and Saldanha-da-Gama, F. *Location Science*, 2019.

[3] Bengio, Y., Lodi, A., and Prouvost, A. Machine learning for combinatorial optimization: a methodological tour d'horizon. *European Journal of Operational Research*, 290(2), 405-421, 2021.

[4] Lodi, A., Mossina, L., and Rachelson, E. Learning to handle parameter perturbations in combinatorial optimization: an application to facility location. *EURO Journal on Transportation and Logistics*, 9(4), 100-203, 2020.

Optimal Mediated Graphs and Where to Find Them: Hidden Combinatorics Underneath Conic Algebraic Geometry

Víctor Blanco [a,b], **Miguel Martínez-Antón** [b,*]

[a] Dpt. Quant. Methods for Economics & Business, University of Granada, Spain, vblanco@ugr.es
[b] Institute of Mathematics University of Granada (IMAG), Spain, mmanton@ugr.es
[*] Presenting author.

Keywords: Mediated Sets, Second–Order Cones, Sums of Squares, Sums of Nonnegative Circuits, Conic Optimization

Introduction

In this proceeding, we provide a unified definition of *mediated graphs*, a combinatorial structure with multiple applications in mathematical optimization, convex geometry, and real algebraic geometry –what is known as *convex algebraic geometry*–, and closely related to the concept of *mediated set* [2]. We study the first geometric and algebraic properties of this novel family of graphs and analyze extremal –which will mean *optimal* later– mediated graphs under the partial order induced by the cardinality of their vertex sets. We derive mixed integer linear programs (MILP) to compute these challenging graphs and show that these structures are crucial in different fields, such as determining a minimal second–order cone programming (SOCP) formulations for optimization problems over generalized power cones, or computing a sum of squares decomposition of nonnegative polynomials supported on circuits, or even certifying if a decomposition like that exists. Hence the close relationship between mediated graphs and *conic* algebraic geometry. In the end, we report the results of an extensive battery of experiments to show the validity of our approaches.
Let $\mathbb{M} \subseteq \mathbb{R}^n$ and $\mathcal{A} \subset \mathbb{M}$ be a finite set. An $\mathbb{M}$–geometric directed graph $G = V, A$ is said an $\mathcal{A}$*–mediated graph* if $\mathcal{A} \subset V$, $\delta v \neq \emptyset$, and if $w \in \delta v$, then $2v - w \in \delta v$, for all $v \in V \backslash \mathcal{A}$.

Let $\mathcal{A} = \{0, 0, 7, 0, 0, 7\}$ (red dots) in Figure 1 we show two different $\mathcal{A}$–mediated graphs in two different domains. In the left picture, we show a $\mathcal{A}$–mediated graph constructed on $\mathbb{M} = \mathbb{R}^2$. Note that, apart from the points in $\mathcal{A}$, four more vertices appear in the graph (blue dots), namely $0.5, 0.5, 1, 1, 2, 2$, and $3.5, 3.5$, all of them midpoints of two other vertices in the graph. The arrows indicate the arcs in the graph, each of them directed from the vertex to the two other vertices for which it is a midpoint. In the right picture, we show an example of a $\mathcal{A}$-mediated graph with domain $\mathbb{M} = \mathbb{Z}^2$. In this case, the graph consists of 10 vertices (3 of them those in $\mathcal{A}$), but the coordinates of the points are now integer numbers. In this case, the vertices not in $\mathcal{A}$ are: $1, 0$, $1, 1$, $1, 2$, $2, 0$, $2, 4$, $4, 0$, and $4, 1$.

The family of mediated graphs can be endowed with a partial order induced by the cardinality

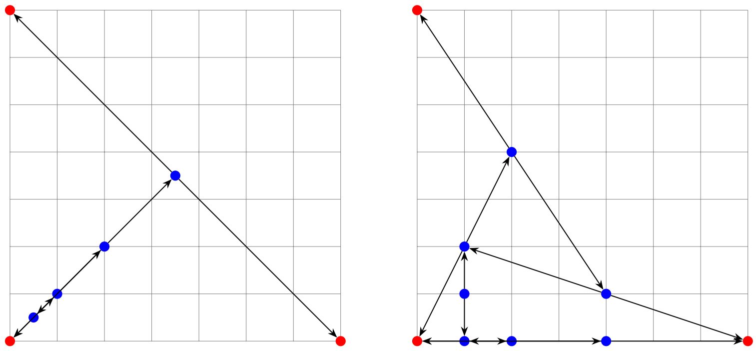


Figure 1: Two versions of $\mathcal{A}$–mediated graphs but with different vertex domains. $\mathbb{R}^2$ (left) and $\mathbb{Z}^2$ (right).

of their vertex sets. Specifically, given $\mathcal{A}$–mediated graphs $G = V, A, G' = V', A'$:

$$G \preceq G' \text{ if and only if either } |V| < |V'| \text{ or } G = G'.$$

Based on this partial order, the family of $\mathcal{A}$–mediated graphs for a given finite set $\mathcal{A} \subset \mathbb{M}$ has two distinguished elements that arise when minimizing and maximizing the number of vertices in the graph.

On the one hand, let $\mathcal{B}$ be another subset of $\mathbb{M}$ a *minimal $\mathcal{A}$–mediated graph* for $\mathcal{B}$ is one that is minimal, under the order $\preceq$, among all $\mathcal{A}$–mediated graph which contains $\mathcal{B}$ in their vertex set.

On the other hand, a *maximal $\mathcal{A}$–mediated graph* is one that is maximal under the order $\preceq$. Notice that an element like this can only exist if $\mathbb{M}$ is a discrete domain, as a lattice.

Now, the questions are:

1. Where can we find optimal mediated graphs?
2. What do we do with them?

Bibliography

[1] Blanco, V., and Martínez-Antón, M. Optimal Mediated Graphs: The role of Combinatorics in Conic Optimization. *arXiv preprint arXiv:2502.03288*, 2025.

[2] Reznick, B. Forms derived from the arithmetic-geometric inequality. *Mathematische Annalen*, 283(3), 431–464, 1989.

Maximal Covering Location Problem with Random Utilities for Urban Recycling: Modeling User Behavior and Bin Overflow Constraints

Gonzalo Méndez-Vogel [a,*], **Sebastián Dávila-Gálvez** [b], **Pedro Jara-Moroni** [c], **Jorge Zamorano** [b]

[a] Department of Engineering Sciences, Universidad Andres Bello, Chile, gonzalo.mendez@unab.cl,
[b] Industrial Engineering Department, Universidad de Santiago, Chile, sebastian.davila@usach.cl, jorge.zamorano.f@usach.cl
[c] Department of Economics, Universidad de Santiago, Chile, pedro.jara@usach.cl
[*] Presenting author.

Keywords: maximal covering location problem, urban recycling, random utilities

Abstract

In the well-known maximal covering location problem, a given number of facilities are located to maximize captured demand. The users' decision rule in this model is binary: demand is assigned to the nearest facility when this is within a predetermined radius. However, in a recycling context—where facilities represent recycling bins, and demand corresponds to the amount of recyclable material generated and deposited by users—this binary rule has certain limitations. First, a user within the coverage radius does not necessarily recycle due to a lack of interest or time. Second, choosing a recycling bin is not always based solely on proximity; factors such as street lighting and the surrounding environment may influence the user's decision. Third, users outside the coverage radius may still recycle, although with a lower probability. Additionally, since recycling bins have limited capacity and users are unaware of their status before visiting, overflow occurs when a full bin continues to receive waste, preventing its proper recycling. In order to address these limitations, this study introduces a probabilistic decision rule based on the multinomial logit model. Soft constraints are also incorporated to model user behavior in response to bin overflow, aiming to maximize the amount of recycled material while minimizing uncollected waste. A mixed integer nonlinear program is proposed and solved through a linear reformulation using a branch-and-cut approach. Finally, location patterns are analyzed in a case study conducted in Estación Central, Santiago, Chile, yielding results consistent with real-world observations.

Collection points placement in urban delivery: A game-theoretic analysis of public and competitive strategies

Fabio Mercurio [a,*], **Margarida Carvalho** [b,c], **Sonja U.K. Rohmer** [b], **Loe Schlicher** [a], **Tom Van Woensel** [a]

[a] Department of Industrial Engineering and Innovation Sciences, Eindhoven University of Technology, Eindhoven, The Netherlands, f.mercurio@tue.nl, l.p.j.schlicher@tue.nl, t.v.woensel@tue.nl
[b] Département de gestion des opérations et de la logistique, HEC Montréal, Montréal, Québec, Canada, sonja-ursula-katharina.rohmer@hec.ca
[c] Département d'informatique et de recherche opérationnelle, Université de Montréal, Montréal, Québec, Canada, carvalho@iro.umontreal.ca
[*] Presenting author.

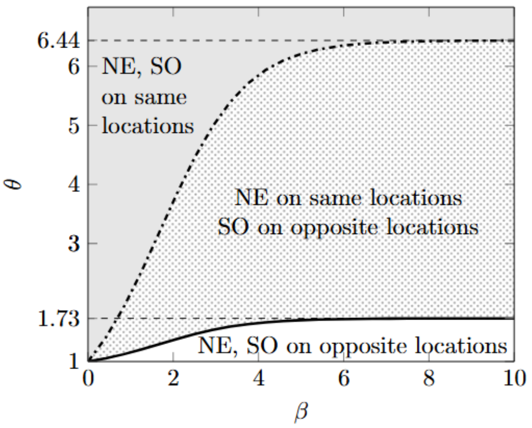
Keywords: Competitive location, Collection points, Nash equilibria

Abstract

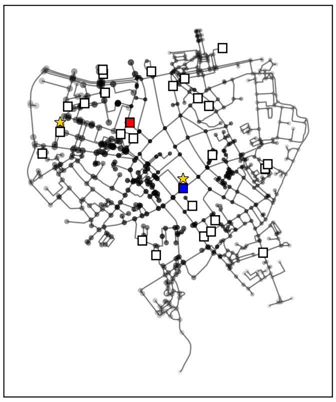
Collection points (CPs), such as parcel lockers and staffed service points, serve as designated locations for the delivery and retrieval of parcels. Competing service providers, e.g. DHL or UPS, establish collection points for consolidating deliveries and enhancing operational efficiency, while public authorities promote them to reduce environmental impact and improve urban living conditions. However, strategic placement decisions from service providers may not align with public interest objectives. Our work investigates two key questions: (i) how service providers strategically position their CPs considering competitive interactions and (ii) how this outcome, driven by service providers maximizing their individual market shares, differs from an optimal placement by a central authority optimizing social welfare (i.e., total market share).

To address these two questions, we develop a game-theoretical model where two competing service providers place CPs within a network of city districts, with customer preferences modeled via the multinomial logit (MNL) framework. Given the locational flexibility of CPs, we assume simultaneous decision-making and explore both Nash equilibria (NEa) as well as social optima (SOa). Moreover, we measure the price of stability by comparing the total market share at the NE to the SO. In doing so, we also examine the percentage of customers using CPs, including the possibility of customers opting out, and quantify potential inefficiencies arising from uncoordinated strategies of CP providers. In this context, we first investigate a stylized two-district setting providing theoretical insights on when CPs are located in the same district according to customers' willingness to use CPs, travel sensitivity, and the districts' population. Figure 2a provides an example of locational outcomes of CPs at the NE and at the SO. In addition, we propose a real-life inspired simulation based on a city in the Netherlands, further examining the impact of customers' CP willingness (denoted by α) and

travel sensitivity (denoted by β) on CP utilization. Figure 2b provides a geographical example of the placements and consequent market shares, while Table 2c provides the market shares at the NE and the loss of the NE with respect to the SO for the proposed willingness and travel sensitivity. The results confirm the stylized model's insights, highlighting possible mismatches between competitive equilibria and socially optimal outcomes.



(a) Location choices of CPs in the stylized two-district setting for the combinations of travel sensitivity β and population ratio θ, i.e., the number of inhabitants in the most populated region divided by the number of inhabitants in the least populated region. Willingness α is given.



(b) Population use of CPs at the NE in the city center of Eindhoven for given α and β. White squares represent possible CP locations, colored squares are the companies' choices at the NE. Darker nodes represent a higher percentage of customers using CPs. Finally, stars correspond to selected CP locations at the SO.

		α											
		-1		0		1		2		3		4	
β	1 km^{-1}	29.4%	-	52.84%	-	75.11%	-	89.07%	0.01%	95.67%	0.01%	98.36%	0.0%
	2	19.6%	-	39.06%	0.17%	62.6%	0.67%	81.51%	0.55%	92.17%	0.29%	96.94%	0.12%
	3	13.0%	-	27.72%	0.89%	49.02%	2.11%	70.7%	2.03%	86.1%	1.25%	94.23%	0.58%
	4	9.03%	-	20.31%	-	36.87%	4.46%	58.08%	4.31%	76.97%	3.26%	89.34%	1.8%
	5	6.35%	3.88%	15.27%	-	30.36%	-	49.18%	1.82%	69.92%	-	81.67%	4.11%
	6	5.06%	-	11.73%	-	24.08%	-	41.54%	-	59.42%	1.66%	77.35%	-
	7	4.13%	-	8.79%	5.18%	19.3%	-	34.46%	-	52.16%	-	68.22%	0.84%
	8	3.43%	0.74%	7.37%	4.78%	15.76%	-	28.69%	-	44.87%	-	58.78%	3.96%
	9	2.95%	-	6.43%	2.71%	12.03%	10.0%	24.02%	-	38.6%	-	54.19%	-
	10	2.54%	-	5.58%	2.44%	10.55%	9.2%	20.52%	-	33.25%	-	47.86%	-
	11	2.22%	0.0%	4.9%	2.34%	9.33%	8.65%	17.94%	-	28.73%	-	42.24%	-
	12	1.96%	0.04%	4.34%	2.32%	8.31%	8.27%	16.0%	-	25.14%	-	37.31%	-

(c) Use rate at the NE (first) and NE loss with respect to the SO (second, corresponding to (1-NE/SO)·100%) of CPs for each combination of proposed α and β in the case study of Eindhoven.

Figure 2: Stylized and case study example of locations of CPs.

Bibliography

[1] Drezner, Z. and Eiselt, H.A. Competitive location models: A review. *European Journal of Operational Research*, Volume 316, Issue 1, 1 July 2024, Pages 5-18.

[2] Janinhoff, L., Klein, R., Sailer, D., and Schoppa, J.M. Out-of-home delivery in last-mile logistics: A review. *Computers & Operations Research*, Volume 168, 2024.

Stochastic facility location problem with outsourcing costs

Eduardo Moreno [a,b,c,*], **Javiera Barrera** [b], **Ivana Ljubić** [c]

[a] Google Research, Paris, France eduardo.moreno@gmail.com
[b] Universidad Adolfo Ibáñez, Santiago, Chile, javiera.barrera@uai.cl
[c] ESSEC Business School, Cergy, France, ivana.ljubic@essec.edu
[*] Presenting author.

Keywords: Stochastic Optimization, Facility Location, Generalized Bender decomposition.

Introduction

Stochastic facility location problems with outsourcing costs (SFLPOC) optimize facility placement and customer assignment under demand uncertainty. Excess demand beyond the capacity of a facility incurs outsourcing costs. This work addresses SFLPOC, aiming to minimize overall expected costs (installation, servicing, and outsourcing). We model SFLPOC as a two-stage stochastic program.

Let y_i be a binary variable representing if facility i is opened at $i \in I$, and let x_{ij} be a binary variable indicating if customer j is assigned to facility i. Then, the problem can be formulated as follows:

$$\min_{x,y} \sum_i f_i y_i \ \mathbb{E}Qx, y, \xi \tag{4a}$$

$$\sum_{i \in I} x_{ij} = 1 \qquad \forall j \in J \qquad \text{(each customer assigned)} \tag{4b}$$

$$x_{ij} \leq y_i \qquad \forall i \in I, j \in J \qquad \text{(assignment to open facilities)} \tag{4c}$$

$$x, y \in \mathcal{X} \qquad \forall i \in I \qquad \text{(additional constrains)} \tag{4d}$$

$$x_{ij}, y_i \in \{0, 1\} \qquad \forall i \in I, j \in J \tag{4e}$$

The function Qx, y, ξ returns the service cost plus the outsourcing cost for the given first stage solution x, y and the random realization of customer demands ξ. For a given point x, y, the value of Qx, y, ξ can be obtained by solving the following second-stage subproblem:

$$Qx, y, \xi := \min_{w} \underbrace{\sum_{i \in I} \sum_{j \in J} s_{ij} w_{ij}}_{\text{Service cost}} \ \underbrace{\sum_{i \in I} \sum_{j \in J} g_{ij} \left(\xi_j x_{ij} - w_{ij} \right)}_{\text{Outsourcing cost}} \tag{5a}$$

$$0 \leq w_{ij} \leq \xi_j \cdot x_{ij} \qquad \forall i \in I, j \in J \tag{5b}$$

$$\sum_{j \in J} w_{ij} \leq K_i \cdot y_i \qquad \forall i \in I \tag{5c}$$

where variable w_{ij} represents the demand of customer j satisfied by facility i.

This problem is presented in [1] for the particular case of independent identically distributed Bernoulli demands, and extended in [3] to other i.i.d. demands. While prior work focused on specific assumptions or small scenario sets, we present methods suitable for general probability distributions. For discrete scenario sets, we improve upon classic Benders decomposition by exploiting the second-stage subproblem's structure. To handle general distributions, we partition the probability space based on incumbent integer solutions. Coupled with Benders cuts and submodular cuts, this provides an exact solution method for common probability distributions. Additionally, we introduce a compact formulation specifically for i.i.d. demand distributions, allowing us to solve even continuous distribution problems to optimality. Computational experiments on established benchmarks demonstrate that our compact formulation consistently finds optimal solutions, while the Benders approach provides strong solutions with proven optimality gaps for general distributions, outperforming other common techniques like sample average approximations.

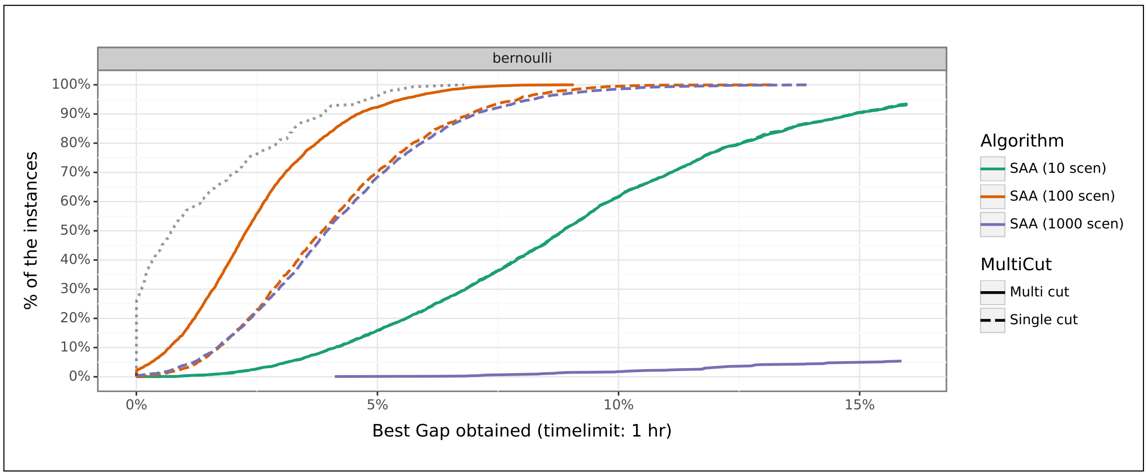


Figure 1: Performance profile of the generalized Bender method versus SAA over instances with heterogeneous Bernoulli demands from Albareda-Sambola et al. (2017).

Bibliography

[1] Albareda-Sambola, M., Fernández, E., and Saldanha-da-Gama, F. The facility location problem with Bernoulli demands. *Omega*, 39(3), 335-345, 2011. `doi:10.1016/j.omega.2010.08.002`.

[2] Albareda-Sambola, M., Fernández, E., and Saldanha-da-Gama, F. Heuristic solutions to the facility location problem with general Bernoulli demands. *INFORMS Journal on Computing*, 29(4), 737–753, 2017. `doi:10.1287/ijoc.2017.0755`.

[3] Bieniek, M. A note on the facility location problem with stochastic demands. *Omega*, 55, 53-60, 2015. `doi:10.1016/j.omega.2015.02.006`.

The Strategic Berth Template Problem with Uncertain Arrival Times

Elena Fernández [a], Manuel Munoz-Marquez [a,*], Francisco Saldanha-da-Gama [b]

[a] Department of Statistics and Operation Research, Universidad de Cádiz, Spain
elena.fernandez@uca.es, manuel.munoz@uca.es
[b] Sheffield University Management School, Sheffield, England, UK
francisco.saldanha-da-gama@sheffield.ac.uk
[*] Presenting author.

Keywords: Strategic Berth Template Problem, Uncertain Arrival Times

Berth allocation problems (BAPs), appear in port operations, and aim at assigning berthing positions and service times to calling ships arriving at a container terminal. Several BAP variants have been considered to take into account, for example, the nature of the berth or the information available on ship arrival times. (see, e.g. [3, 4, 5]). It is actually very common that ships call for service at ports on a regular basis. This further limits the service capacity of the ports, which is largely determined by the number of available berths. When service calls arrive cyclically it may no longer be feasible to accept all the requests, which motivates to study the problem of deciding the ships that should be served. The Strategic Berth Template Problem (SBTP) combines the strategic decisions of determining the ships that should be served, with the operational decisions of establishing when and where they should be served. This is done for a given set of cyclically calling ships providing a template that will be applied in a cyclic fashion in the considered planning horizon. Furthermore, there may be links relating the strategic decisions of service to ships belonging to certain groups. These links are derived from strong transhipment relations between some large-size mother ships and some smaller feeder ships, which are contractually attached to each other. All the ships within each group must be handled similarly, in the sense that all of them are either served or rejected.

In practice, the precise arrival time of ships is usually not known exactly at the planning stage. Then, existing models ignoring such uncertainty might produce infeasible plans. A recent review focusing on uncertainty for BAPs is [7]. The main objective of this work is to study an extension of the SBTP that considers uncertainty in arrival times, that will be called the Stochastic Berth Template Problem or (SSBTP).

The formulation for the SBTP in [6] is considered here as the starting point to include uncertainty in arrival times in the model. As a first step, the above formulation is extended for the worst-case analysis providing our first formulation for the SSBTP. As usual, this approach leads to a very conservative solutions.

Then, a less conservative approach proposed in [1, 2], so called budget uncertainty analysis, is applied. This approach proposes to limit the total amount of uncertainty that must be admitted by any solution proposed by the model. This budget uncertainty is considered as a parameter of the model, which measures the tolerance of solutions to deviations from expected arrival times. Still, it turns out that this methodology, as it stands, reduces once again the problem to a worst-case analysis, without providing any new information on the matter.

Therefore, a custom version of budget uncertainty analysis is considered as a final step. In this analysis, a set of valid inequalities are included in the model in such way that *constrained* budget uncertainty analysis provides a new model. The analysis of this new model involves the solution of an embedded subproblem, which can be integrated in the main formulation using dualization techniques.

The SBTP benchmark instances of [5] are extended to include uncertainty under different hypothesis of uncertainty arrival time distributions. Extensive numerical experiments are conducted over those instances showing the usefulness of this formulation. The cost of including uncertainty in the model is analyzed by showing the relationship between the budget uncertainty parameter and waiting times in the case-based analysis.

Bibliography

[1] Bertsimas, D. and Sim, M. Robust discrete optimization and network flows. *Mathematical Programming Series B*, 98:49–71, 2003.

[2] Bertsimas, D. and Sim, M. The price of robustness. *Operations Research*, 52(1):35–53, 2004.

[3] Bierwirth, C. and Meisel, F. A survey of berth allocation and quay crane scheduling problems in container terminals. *European Journal of Operational Research*, 202(3):615 – 627, 2010.

[4] Bierwirth, C. and Meisel, F. A follow-up survey of berth allocation and quay crane scheduling problems in container terminals. *European Journal of Operational Research*, 244(3):675 – 689, 2015.

[5] Iris, Ç., Lalla-Ruiz, E., Lam, J., and Voss, S. Mathematical programming formulations for the strategic berth template problem. *Computers & Industrial Engineering*, 124:167–179, 2018.

[6] Fernández, E. and Munoz-Marquez, M. New formulations and solutions for the strategic berth template problem. *European Journal of Operational Research*, 298(1):99–117, 2022.

[7] Rodrigues, F. and Agra, A. Berth allocation and quay crane assignment/scheduling problem under uncertainty: A survey. *European Journal of Operational Research*, 303(2):501–524, 2022.

Combined risk attitudes in optimization models

Juan M. Muñoz-Ocaña [a,*], Antonio M. Rodríguez-Chía [a], Francisco Saldanha-da-Gama [b]

[a] Universidad de Cádiz, juanmanuel.munoz@uca.es, antonio.rodriguezchia@uca.es,
[b] Sheffield University Management School, francisco.saldanha-da-gama@sheffield.ac.uk
[*] Presenting author.

Keywords: Stochastic mixed-integer programming, capacitated facility location problem, risk attitudes

Introduction

In this talk, we discuss a stochastic capacitated facility location problem where customer demands are the source of uncertainty. Facility location decisions must be implemented before knowing the demands while distribution decisions are adaptive.
In the literature, the decision-maker typically assumes a risk-neutral or a risk-averse attitude [1, 2]. For the risk-neutral case, which is a common assumption in the facility location literature, decision-makers evaluate future assets based on their expected value, ignoring any variability. Risk-averse decision-makers, on the other hand, prioritize minimizing potential losses over maximizing potential gains, since they prefer to avoid high risks. This attitude can be modeled by minimizing the Conditional Value at Risk for a fixed confidence level α. However, the risk attitude can be opposite, i.e., the decision-makers could be interested in assuming a higher chance of loss in exchange for the possibility of a larger gain. This risk attitude is known as risk seeking and a coherent measure of risk is proposed for this behavior.
We analyze the situation in which the decision-maker exhibits combined risk attitudes, as they may depend on the involved costs. In real-world situations, while, lower expected costs could encourage the decision-maker to acquire a risk-averse attitude, higher expected costs could lead a risk-seeking criterion. The proposed formulation will then determine the appropriate attitude of the decision-maker in the optimal solution according to the involved costs.
Generalizations of these risk attitudes are considered in this talk by incorporating confidence levels into the formulations that depend on the total costs, since risk-averse or risk-seeker decision-makers may present different levels of risk tolerance. Higher expected costs may increase risk aversion while lower expected costs may reduce it. Similarly, lower expected costs may increase risk-seeking behavior.

Bibliography

[1] Fernández, E., Hinojosa, Y., Puerto, J., and Saldanha-da-Gama, F. New algorithmic framework for conditional value at risk: Application to stochastic fixed-charge transportation. *European Journal of Operational Research*, 277, 215-226, 2019.

[2] Li, Y., Liu, M., Saldanha-da-Gama, F., and Yang, Z. Risk-averse two-stage stochastic programming for assembly line reconfiguration with dynamic sizes. *Omega*, 127, 103092, 2024.

A Mathematical Optimization Approach for Multisphere Support Vector Data Description

V. Blanco [a], I. Espejo [b], R. Páez [b,*], A.M. Rodríguez-Chía [b]

[a] Institute of Mathematics (IMAG), University of Granada, Spain, vblanco@ugr.es
[b] Dept. of Statistics & Operations Research, University of Cádiz, Spain,
inmaculada.espejo@uca.es, raul.paez@uca.es, antonio.rodriguezchia@uca.es
[*] Presenting author.

Keywords: Multisphere SVDD, multimodal outlier detection

Introduction

SVDD models were introduced for anomaly detection and one-class classification, as a methodology to recognize patterns in objects presumed as regular, and differentiate them from other objects that do not meet those patterns. This tool is particularly interesting for datasets where identifying outliers and recognizing data boundaries is required. In contrast to other types of classification tools, the labels of the training observations are not provided, and the goal is to distinguish regular data from anomalous instances by means of geometric boundaries. One of the advantages of SVDD is that it allows the construction of flexible description boundaries without the need to make assumptions regarding data distribution. SVDD was introduced by Tax and Duin [1] as a tool for one-class classification based on solving a convex optimization problem. The strong duality of the problem was further analyzed in [2] implying an equivalent dual reformulation of the problem that allows for the use of kernels to construct more sophisticated classification boundaries.

Nevertheless, little attention has been given in the literature to outlier detection methods for multimodal data. That is, the dataset contains instances from different distributions that are to be detected, as well as their outliers. Although the SVDD and their extensions have been proven to be useful to determine the hidden distribution of the given data in case the data comes from a single spatial distribution, these methods fail to detect different distributions. A few works have analyzed the problem of extending SVDD tools to multiple distributions. [3] provide a multi-class SVDD method by assuming the assignments of the training data to the different classes is known (a supervised approach). In [4, 5] the authors propose a new methodology to combine SVDD and clustering approaches to derive a machine learning tool to detect outliers observations in this type of datasets. However, all the previously proposed approaches are heuristic since it consists of separately detect distributions (clustering) and outliers (SVDD).

The main implications of our proposal is that this methodology allows for a optimal and simultaneous clustering and outlier detection approach, able to capture the different trends hidden in the instances of a dataset. In this work we analyze the mathematical optimization insights of this problem that we call the MultiSphere Support Vector Data Description

(MSVDD) problem. We propose a primal mixed integer nonlinear optimization model for the problem that can be reformulated as a Mixed Integer Second Order Cone Optimization (MISOCO) problem. Then, we derive a dual reformulation that allows for the use of the kernel trick. We conclude some mathematical properties of the problem and analyze its ability to detect outlier observations in multimodal instances.
We run a series of computational experiments to validate our proposal compared with the heuristic location-allocation approach proposed in [4].

Bibliography

[1] Tax, D.M.J. and Duin, R.P.W. Support vector data description. *Machine learning*, 54, 45-66, 2004.

[2] Wang, X., Chung, F., and Wang S. Theoretical analysis for solution of support vector data description. *Neural Networks*, 24(4), 360-369, 2011.

[3] Turkoz, M., Kim, S., Son, Y., Jeong, M.K., and Elsayed, E.A. Generalized support vector data description for anomaly detection. *Pattern Recognition*, 100, 107-119, 2020.

[4] Görnitz, N., Lima, L.A., Müller, K.R., Kloft, M., and Nakajima, S. Support vector data descriptions and *k*-means clustering: one class?. *IEEE transactions on neural networks and learning systems*, 29(9), 3994-4006, 2017.

[5] Xiao, Y., Liu, B., Cao, L., Wu, X., Zhang, C., Hao, Z., Yang, F., and Cao, J. Multi-sphere support vector data description for outliers detection on multi-distribution data. *2009 IEEE international conference on data mining workshops*, 82-87, 2009.

Preliminary results on the generalized vertex cover problem

Juan Francisco Correcher [a], Mercedes Landete [b], Juanjo Peiró [a,*], Hande Yaman [c]

[a] Universitat de València, Spain, juan.correcher@uv.es, juanjo.peiro@uv.es,
[b] Universidad Miguel Hernández de Elche, Spain, landete@umh.es
[c] Katholieke Universiteit Leuven, Belgium, hande.yaman@kuleuven.be
[*] Presenting author.

Keywords: vertex selection, edge covering, graph decomposition.

Introduction

The generalized vertex cover problem (GVC) extends the classical vertex cover problem by incorporating penalties for uncovered edges (see, among others, [1, 2]). This $\mathcal{NP}$-hard problem arises in various practical domains, including network design, logistics, and resource allocation. In this talk, we propose a comprehensive framework for addressing the GVC, presenting some theoretical results and algorithms. To simplify and efficiently solve the problem, we propose a decomposition technique that leverages the structural properties of graphs, including articulation points and tree-based structures. We develop some algorithms and assess their performance with state-of-the-art benchmarks. Our computational experiments show that the proposed methods outperform existing approaches in both solution quality and runtime.

Bibliography

[1] Hochbaum, D. Approximation algorithms for the set covering and vertex cover problems. *SIAM Journal on Computing*, 11(3), 555-556, 1982.

[2] Pandey, P. and Punnen, A. P. The generalized vertex cover problem and some variations. *Discrete Optimization*, 30, 121-143, 2018.

Optimal location of synchronization servers and robust radio base concentrator assignation in telecommunications networks

Pedro Piñeyro [a,*], Antonio Mauttone [a], Federico Molina [b], Enrique Munné [b], Alejandro Pascual [b], Carlos Testuri [a]

[a] Department of Operations Research, Computer Science Institute (InCo),
Facultad de Ingeniería, Universidad de la República, Uruguay.
mauttone@fing.edu.uy, ppineyro@fing.edu.uy, ctesturi@fing.edu.uy,
[b] National Telecommunications Administration (ANTEL), Uruguay.
emunne@antel.com.uy, fmolina@antel.com.uy, apascual@antel.com.uy
[*] Presenting author.

Keywords: Capacitated Facility Location Problem, Telecommunications Networks, Precise Time Synchronization

Introduction

In mobile networks, base stations need to synchronize their clock frequency and time with reference clocks (synchronization servers) distributed in the network. This can be achieved by using the IEEE 1588 Precision Time Protocol (PTP) [3]. In this paper we tackle the problem of determining the number and location of PTP synchronization servers in a telecommunications network, in order to meet the demand and technical requirements detailed below, minimizing the acquisition costs of the servers. The demand is determined by the number of base stations connected to the network through concentrators. For each concentrator, a primary server and a secondary server must be assigned for the synchronization of all the base stations connected to it. The closest server (in number of network hops) of the two selected for the concentrator must be designated as the primary server, and the remaining one as the secondary. The assigned servers cannot exceed a preset limit in network hops and it is desirable that the number of hops (distance) be as small as possible. There are several different types of PTP synchronization servers, depending on acquisition costs and synchronization capacity. Multiple servers can be installed at a site, but only one of a given type. In addition, the primary and secondary servers of a concentrator are required to be located at different sites in the network. We refer to this optimization problem as the Location Problem of PTP Synchronization Servers (LP-PTPSS). This research was carried out with the support of the Uruguayan state telecommunications company, ANTEL.

Solution approach

To solve the LP-PTPSS, we propose a Capacitated Facility Location Problem (CFLP) model [5], in which each concentrator is simultaneously assigned to a primary and a secondary synchronization server. To do this, the demand on the concentrators is doubled, and the supply of an assigned server is required to be exactly half this amount. A constraint proposed in [2] and introduced in [1] is used to ensure that the total capacity of the installed servers is at least equal to the total demand. Although this constraint is redundant, according to [1], it can be useful to reduce the model resolution times.

Numerical results

The proposed model for the LP-PTPSS was used to solve different instances of interest based on real data with a single type of synchronization server, including load balancing of the servers installed as in [4]. The network considered has 243 possible sites for server installation and 852 concentrators with demand values ranging from 0 to 42 base stations. The model was coded in AMPL and solved with Gurobi 11.0.0 on a computer with 18 Intel(R) Core(TM) i9-10980XE 3.00GHz CPUs and 125 GB of RAM. A time limit of 1800s and an optimality gap of 0% were set for Gurobi. For example, Table 1 shows a summary of the results obtained for the models with ("Model+") and without ("Model") the redundant constraint of [2], for demand increases of 10%, 20%, 30%, 40% and 50% respectively, and a maximum number of seven network hops allowed. Columns "Time (s)" show the execution time, in seconds, at which the solution returned by the solver was first found in the case of a positive optimality gap, or the total execution time in the case of gap equal to zero.

	Model+				Model			
Dem.	# Srv	Obj.Val.	Time (s)	% Gap	# Srv	Obj.Val.	Time (s)	% Gap
+0%	8	168341	20.382	0.00%	8	168341	232.000	4.80%
+10%	10	209119	73.020	0.00%	10	209119	940.000	7.00%
+20%	10	210165	91.008	0.00%	10	210175	125.000	2.72%
+30%	11	229084	38.620	0.00%	11	229086	1169.000	5.48%
+40%	12	249612	158.684	0.00%	12	249647	1094.000	5.98%
+50%	12	250839	270.093	0.00%	12	250841	1381.000	2.58%

Table 1: Results for demand increases and up to seven network hops.

From Table 1, we can note that the number of servers ("# Srv") increases as the demand does and that even in the case of a 10% increase, a 25% increase in the number of synchronization servers would be necessary. Regarding execution times, we can observe that in general they increase as demand does, although the model with the redundant constraint of [2] does so to a much lesser extent than the one initially proposed. In fact, for the model with the [2] constraint, optimality is achieved for all instances, even in the extreme case of a 50% increase in demand values.

Bibliography

[1] Aardal, K. Reformulation of capacitated facility location problems: How redundant information can help. *Annals of Operations Research*, 82, 289-308, 1998.

[2] Avella, P., Boccia, M., Mattia S. and Rossi F. Weak flow cover inequalities for the capacitated facility location problem. *European Journal of Operational Research*, 289(2), 485-494, 2021.

[3] IEEE 1588. IEEE Standard for a Precision Clock Synchronization Protocol for Networked Measurement and Control Systems. IEEE Instrumentation and Measurement Society, 2008.

[4] Marín, A. The discrete facility location problem with balanced allocation of customers. *European Journal of Operational Research*, 210(1), 27-38, 2011.

[5] Verter, V. Uncapacitated and Capacitated Facility Location Problems. *Foundations of Location Analysis*, H.A. Eiselt and V. Marianov (eds), New York, Springer US, 25-37, 2011.

On geodesic problems in location analysis: location with distance dependent regions

Justo Puerto

Universidad de Sevilla, puerto@us.es

Keywords: Continuous location, Geodesic, Weighted region problem

Introduction

The weighted region problem (WRP) is a generalization of the shortest path problem considered in a geometric domain where the travel distance is region-dependent. More precisely, given a subdivision of the plane in polyhedra with different associated weights, the WRP asks for the Euclidean shortest path between two points but taking into account that the distance traversed along a polyhedron has to be multiplied by its associated weight. The WRP was originally introduced in [9] and, besides its mathematical interest, it was motivated as a model to design the route of robots through zones with different terrains that are traversed at different speeds (e.g. grassland, blacktop, water, et cetera). Other practical applications of the WRP have been proposed for instance in geographical information systems (GIS) and in Seismology (see [4]) The WRP has been generalized in many directions, allowing, among others, general cost functions in different regions with application to terrain navigation problems coming from practical problems within the DARPA project.

In this paper we consider two different problems: 1) a variant of the location Problem with different ℓ_p-norms (ℓ_p-WRP), where each polyhedron of the subdivision is endowed with a different ℓ_p-norm, $1 \leq p \leq \infty$ and it is assumed that paths are allowed to visit each polyhedron, at most, once; and 2) the single facility Weber location problem. We study the variant of the WRP not only in the plane, but also in $\mathbb{R}^d$. As an intuitive qualitative criterion, we restrict feasible paths to visit each polyhedron at most once, which in turn implies that the paths are simple in the dual graph of the subdivision. Later we extend the analysis to any finite number of visits. Apart from the mathematical interest that motivates this paper, there are also interesting applications that justify the use of different norms. For instance, in general terrain-urban navigation it is natural the combination of ℓ_1-norm for urban setting and ℓ_2-norm for rural areas. Or more generally, the use of other ℓ_p-norms to model actual road distances as pointed out in [1, 7, 6]. Also in the routing of vessels among region-varying weather patterns in the ocean [10].

We propose a solution scheme for the problem completely different from the ones proposed for the WRP and its variants previously considered. This scheme consists in the representation of the problem as a mixed-integer second order cone problem (MISOCP), which is achieved using the ℓ_p-norms modeling procedure given in [2, 3]. MISOCPs can be solved nowadays up to any degree of accuracy with commercial solvers. Therefore, we propose an approximate method with a high precision degree whose accuracy is only compromised by the rounding error inherent to computers and the internal algorithms used in solvers' implementations. In particular we present two MISOCP formulations for the problem, theoretically compare their properties, and propose a preprocessing scheme to improve their performance. The performance of the formulations and the preprocessing are evaluated on a testbed of instances. We also discuss how the developed MISOCP formulations can be adapted to deal with two extensions of the problem: the case when rapid transit boundaries (at times called in the literature *roads*, see [5, 8]) are considered and the case of non-simple paths. These extensions can be handled by applying a simple transformation to the input data, which shows the flexibility of our approach. This paper does not directly address the complexity of the problem. Moreover, the methods developed in this paper are not poly-time and their dependence on the number of considered regions is similar to other approaches based on mixed-integer programs (presumably worst-case exponential).

Bibliography

[1] Berens, W. The suitability of the weighted ℓ_p-norm in estimating actual road distances. *European Journal of Operational Research*, 34, 39-43, 1988.

[2] Blanco, V., Puerto, J., and El-Haj Ben-Ali, S. Revisiting several problems and algorithms in continuous location with ℓ_τ norms. *Computational Optimization and Applications*, 58(3), 563-595, 2014.

[3] Blanco, V., Puerto, J., and Ponce, D. Continuous location under the effect of 'refraction'. *Mathematical Programming*, 161(1-2), 33-72, 2017.

[4] Gheibi, A., Maheshwari, A., Sack, J. R., and Scheffer, C. Path refinement in weighted regions. *Algorithmica*, 80(12), 3766-3802, 2018.

[5] Laxmi P. Gewali, Alex C. Meng, Joseph S. B. Mitchell, and Simeon C. Ntafos. Path planning in 0/1/ weighted regions with applications. *INFORMS J. Comput.*, 2(3):253–272, 1990.

[6] Love, R.F. and Morris, J.G. Mathematical models of road travel distances. *Management Science*, 25, 130–139, 1972.

[7] Krarup, J. and Pruzn, P.M. *The impact of distance on location problems*. *European Journal of Operational Research*, 4, 256–269, 1980.

[8] Joseph S. B. Mitchell. Shortest paths among obstacles, zero-cost regions, and "roads". Technical Report 764, School Oper. Res. Indust. Engrg., Cornell Univ., Ithaca, NY, 1987.

[9] Mitchell, J. S., Papadimitriou, C. H. The weighted region problem: finding shortest paths through a weighted planar subdivision. *Journal of the ACM (JACM)*, 38(1), 18-73, 1991.

[10] Papadakis, N. A., and Perakis, A.N. "Deterministic Minimal Time Vessel Routing." *Operations Research,* 38(3), 426–38, 1990.

Dynamic Programming and Block-Cut Tree Decompositions for the Maximum Covering Network Design Problem

Felix Rauh [*], Jannik Matuschke, Hande Yaman

KU Leuven, felix.rauh@kuleuven.be, jannik.matuschke@kuleuven.be, hande.yaman@kuleuven.be
[*] Presenting author.

Keywords: maximum covering location problem, network design problem, dynamic programming

Introduction

In order to plan accessible public health services and resilient infrastructure, high quality solutions to network design and facility location problems are of utmost importance. We tackle a problem that arises, for instance, when improving health care access in areas that are prone to disruptions such as recurring floods. A given budget can then be used both for building new hospitals as well as making weak links in the network resilient to floods. The goal is to maximize the number of households that can reach a facility via a flood-resilient access of, e.g., at most five kilometers.

Problem Formulation

We define our variant of the *Maximum Covering with Network Design Problem (MCNDP)* as follows: Given a graph $G = V, E$ with vertex weights w, edge cost c^E and facility cost c^F, we aim to choose a set of links $X \subseteq E$ and facilities $Y \subseteq V$ such that the total weight of vertices that are within distance $\overline{d}$ to an open facility is maximized. In particular, we allow that c^E and c^F are zero for existing links and facilities, or that $c_i^F = \infty$ if location i is not a potential facility location. The total allocated budget needs to be bounded by $\overline{b}$, i.e., it must hold that $\sum_{i \in Y} c_i^F \ \sum_{e \in X} c_i^E \leq \overline{b}$.
While there is one recent Benders decomposition approach by Bucarey et al. that can be applied to our problem variant [1], previous work on this combination of network design and maximum covering with a combined budget is limited. For a classification and overview of work on a wide range of combinations and variants of network design as well as maximum covering, we refer to [2] and [3, 4].

Contribution

In this talk, we present an exact solution framework for the MCNDP based on dynamic programming (DP), and describe its theoretical properties as well as computational performance. First, we show that the problem on trees allows for an optimal solution approach via dynamic programming that is pseudo-polynomial in the given budget. The method is an extension of DP approaches to the maximum covering and p-median problem [5, 6]. Computational

comparisons with two different formulations solved by a commercial solver show that the DP is superior in specific situations.
A more general class of graphs that is of interest are graphs that have cut vertices (so-called articulation points). Such graphs allow for a non-trivial decomposition into a *block-cut tree (BC tree)*, where the maximal biconnected components of the graph (i.e., the *blocks*) correspond to the vertices in the BC tree. According to Tian et al., the BC tree is non-trivial for many real-world networks [7]. Motivated by the DP on trees, we introduce an exact approach for the MCNDP that uses BC trees. While essentially any given approach or MIP formulation can be used for partial solutions on blocks, the DP identifies the optimal way to combine these and allocate the budget. Our ongoing work improves on that by using primal and dual bounds on the blocks to create a fast heuristic as well as optimal solutions in a branch and bound fashion.
We present the computational benefits of the approach via preliminary results of an extensive computational study that compares our approach, e.g., with a branch and cut approach that uses the idea of length-bounded cuts.

Bibliography

[1] Bucarey, V., Fortz, B, González-Blanco, N., Labbé, M., and Mesa J. A. Benders decomposition for network design covering problems. *Computers & Operations Research*, 137:105417, January 2022.

[2] Contreras, I. and Fernández, E., 2012. General network design: A unified view of combined location and network design problems. *European Journal of Operational Research*, Feature Clusters 219, 680–697.

[3] Crainic, T. G., Gendreau, M., and Gendron, B. editors. *Network Design with Applications to Transportation and Logistics*. Springer International Publishing, Cham, 2021.

[4] García S. and Marín A. Covering Location Problems. In Gilbert Laporte, Stefan Nickel, and Francisco Saldanha da Gama, editors, *Location Science*, pages 99–119. Springer International Publishing, Cham, 2019.

[5] Megiddo, N. Zemel, E., and Hakimi S. L. The Maximum Coverage Location Problem. *SIAM Journal on Algebraic Discrete Methods*, June 1983.

[6] Tamir, A. An $O(pn^2)$ algorithm for the p-median and related problems on tree graphs. *Operations Research Letters*, 19(2):59–64, August 1996.

[7] Tian, L., Bashan, A., Shi, D.-N., and Liu, Y.-Y. Articulation points in complex networks. *Nature Communications*, 8(1):14223, January 2017.

Cargo allocation problem on road transport subject to driving-time regulations

I. Espejo, J.M. Muñoz-Ocaña, T. Navarro R. Páez, A.M. Rodríguez-Chía*

Departamento de Estadística e Investigación Operativa, Universidad de Cádiz, Facultad de Ciencias, 11510, Puerto Real (Cádiz), Spain. inmaculada.espejo@uca.es, juanmanuel.munoz@uca.es, teresa.navarro@uca.es, raul.paez@uca.es, antonio.rodriguezchia@uca.es
* Presenting author.

Keywords: mixed-integer linear formulation, times windows, road transportation

Introduction

The existing literature on optimizing road freight transport is commonly based on the Vehicle Routing Problem (VRP), which involves determining a cost-minimal set of routes for a fleet of vehicles that ensure a given set of customers is visited while complying with all operational constraints, [2, 4]. In the VRP with time windows (VRPTW), deliveries need to take place within a specified time slot [1]. The variant of the VRPTW with working regulation is called Vehicle Routing and Driver Scheduling Problem (VRDSP). This type of vehicle routing problems usually considers a specific sequence of locations, which defines the order in which clients are visited within their time window. This sequence can be determined based on specific criteria, such as minimizing cost, time, or distance. Once the sequence has been established, the problem to be solved is to determine a driver's schedule in accordance with the applicable regulation [3, 5].

We propose to analyze a similar problem from a different perspective where, given a set of cargos (origin/destination) with time windows for loading (at the origin) and unloading (at the destination) and a set of available drivers/trucks to fully or partially cover these cargos, the goal is to optimally assign these cargos to the drivers/trucks. Optimally refers to maximizing benefits taking into account the feasibility conditions given by the limitations of driving-time imposed by the current regulation (in our case, the European Union regulation) and the time windows of these cargos. Observe that several cargos could be assigned to the same driver/truck whenever the driving limitations and the time windows allow it, but on the contrary one cargo could be assigned at most to one driver/truck or even not be assigned. This paper presents a branch-and-bound-and-cut solution method to solve the proposed problem based on a formulation that models this problem with a relaxation in the computation of driving-time windows. In addition, since the driving-times and rest-periods defined by the regulation allow for a large number of possible combinations, different versions of this solution method are explored which respond to several levels of reduction in the flexibility to define the daily driving-time set by the regulation. A computational analysis of these different versions of the solution methods are carried out, including a comparison of the objective values and running times.

Bibliography

[1] Cordeau, J.-F., Laporte, G., and Mercier, A. A unified tabu search heuristic for vehicle routing problems with time windows. *Journal of the Operational Research Society,* 52(8):928-936, 2001.

[2] Cordeau, J.-F., Laporte, G., Savelsbergh, M. W., and Vigo, D. Vehicle routing. *Handbooks in operations research and management science,* 14:367-428, 2007.

[3] Parragh, S. N., Cordeau, J.-F., Doerner, K. F., and Hartl, R. F. Models and algorithms for the heterogeneous dial-a-ride problem with driver-related constraints. *OR Spectrum,* 34:593-633, 2012.

[4] Toth, P. and Vigo, D. The vehicle routing problem. *SIAM,* 2002.

[5] Wen, M., Krapper, E., Larsen, J., and Stidsen, T. K. A multilevel variable neighborhood search heuristic for a practical vehicle routing and driver scheduling problem. *Networks,* 58(4):311-322, 2011.

Logistics planning for post-disaster resilience assessment under uncertainty

Asena Kaplan [a], Jessica Rodríguez-Pereira [b,*], Burcu Balçik [a], Marie-Ève Rancourt [c] Gilbert Laporte [c,d]

[a] Ozyegin University, asena.kaplan@ozu.edu.tr, burcu.balcik@ozyegin.edu.tr
[b] Universitat Politècnica de Catalunya, jessica.rodriguez@upc.edu
[c] HEC Montréal, marie-eve.rancourt@hec.ca, gilbert.laporte@cirrelt.net
[d] School of Management, University of Bath
* Presenting author.

Keywords: Resilience Assessment, Site Selection, Stochastic Vehicle Routing, Post-disaster

Introduction

Every year, natural and human-made disasters cause extensive loss of life, infrastructure damage, and disruption to livelihoods of the people in the affected areas. The devastating earthquakes that struck southern Türkiye and northern Syria on February 6, 2023, exemplify these impacts, affecting 11 key provinces and over 14 million people in Türkiye. Rapid assessments conducted in the immediate aftermath of such disasters provide crucial insights, revealing the initial situation and understanding the immediate impacts. However, once the initial emergency is managed, further field assessments are often made to gather information on the long-term effects of the disaster, fully understand the changing and newly arising vulnerabilities, and evaluate the ability to withstand and recover from the disruptions caused by the disasters. Field assessments are conducted by visiting affected sites and interviewing key informants. Scheduling and planning these field assessments are essential to efficiently complete these studies.

Problem description

Our study is motivated by a real-life situation in which a logistical plan to conduct detailed assessments in rural areas affected by the earthquakes in Türkiye must be developed. We formulate and solve a problem that integrates both location selection for assessments (ensuring sampling representation) and the routing of field teams while accounting for uncertainties in site availability. Both aspects present unique challenges. On one hand, the selection sample of visited villages must be representative based on their economic, agricultural, demographic, and geographic characteristics. On the other hand, uncertainty in the availability of the key informants to conduct the survey when the team arrives at a selected site must be incorporated into the routing design of the team routes. This is tackle by incorporating backup locations for each selected site, distinguishing between primary and backup villages, and ensuring backup sites maintain representative sampling.

Methodology

While previous literature on humanitarian assessment planning has addressed similar problems through various methods (e.g., [1]; [2]; [3]), our approach employs a novel clustering method for sampling. This involves large-scale data collection and analysis to group villages based on similarities, and formulating a new integrated sampling and routing problem. We develop an efficient matheuristic utilizing a set-partitioning model on enumerated routes, capable of handling realistic problem instances and addressing the computational challenges posed by the problem's complexity. Our approach is tested through a case study based on real-world data from the 2023 Türkiye earthquakes.

Bibliography

[1] Balcik, B. Site selection and vehicle routing for post-disaster rapid needs assessment. *Transportation Research Part E: logistics and transportation review*, 101, 30–58, 2017.

[2] Balcik, B. and Yanıkoğlu, İ. A robust optimization approach for humanitarian needs assessment planning under travel time uncertainty. *European Journal of Operational Research*, 282(1), 40–57, 2020.

[3] Pamukcu, D., and Balcik, B. A multi-cover routing problem for planning rapid needs assessment under different information-sharing settings. *OR Spectrum*, 42(1), 1–42, 2020.

Optimizing the Location of Waste Transfer Stations and Treatment Facilities for Sustainable Urban Solid Waste Management

Krystel M. Rodríguez [a,*], José-Fernando Camacho-Vallejo [a], Rosa G. González-Ramírez [b], Juan G. Villegas [c]

[a] Tecnológico de Monterrey, Escuela de Ingeniería y Ciencias, Mexico,
a00843309@tec.mx, fernando.camacho@tec.mx
[b] Facultad de Ingeniería y Ciencias Aplicadas, Universidad de los Andes, Chile,
rgonzalez@uandes.cl
[c] ALIADO-Analytics and Research for Decision Making, Department of Industrial Engineering, Universidad de Antioquia, Colombia, juan.villegas@udea.edu.co
[*] Presenting author.

Keywords: Solid Waste Management, Facility Location, Bi-level programming

Introduction

Urban solid waste (USW) management is becoming increasingly challenging due to population growth and urbanization. In developing nations, low recycling rates result from inadequate infrastructure and inefficient decision-making. Mathematical optimization models provide valuable policy guidance for waste management [1]. Additionally, facility location problems are often integrated with assignment or routing models to balance costs, greenhouse gas emissions, and environmental impact [2]. Specifically, bi-level programming has gained relevance in sustainability research, demonstrating its suitability for hierarchical decision-making in USW management [3].

Based on this foundation, this study proposes a bi-level location optimization model for urban solid waste collection and management, focusing on the hierarchical supply chain of transfer stations and specialized treatment facilities. The model captures the decision-making processes of two key stakeholders: the government, which determines the optimal location of transfer stations to minimize carbon dioxide (CO_2) emissions; and a private company, which optimizes waste transportation, plant specialization and operational costs. To efficiently solve this hierarchical location problem, a novel matheuristic algorithm based on nested local search is developed. This approach integrates a deconstructive strategy to generate upper-level solutions while ensuring feasibility through the optimal resolution of the lower-level problem.

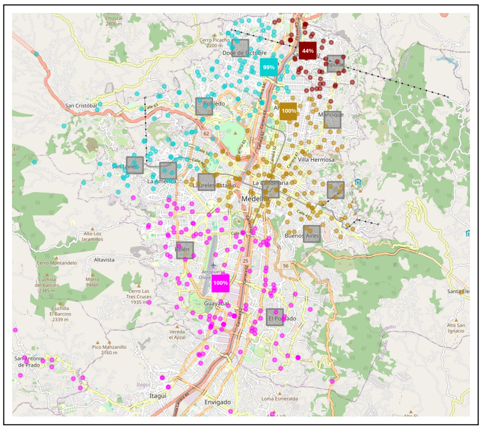
Case Study

Using the city's waste management plan and secondary sources, a real-world case study from Medellín, Colombia, is analyzed considering organic residues, glass, plastic, paper, and cartons in a supply chain with 547 collection zones, 16 transfer stations, 42 treatment plant locations, and a landfill for untreated waste. We first evaluate each USW type to determine the ratio R, which prioritizes processing based on the cost per kilogram of avoided CO_2 emissions. Results in Table 1 indicate that first integrating plastic into the system, the highest CO_2 reduction is achieved at the lowest cost.

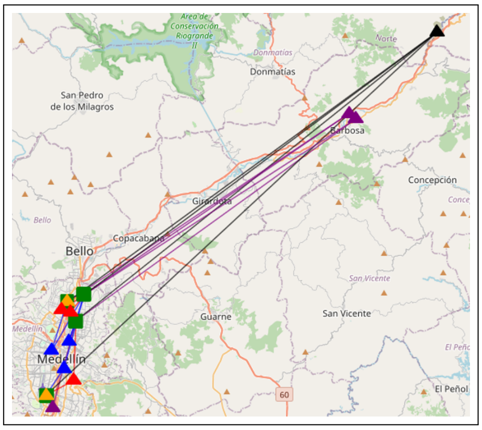
USW Type	Avoided emissions (kgCO_2)	Cost ($)	R
Organic waste	136,582.60	85,132,545,954.31	1.60
Paper & cartons	121,471.61	1,971,255,707.37	61.62
Plastic	170,789.08	1,929,650,457.64	88.51
Glass	20,384.89	1,972,321,555.29	10.34

Table 1: Avoided CO_2 emissions and cost ratio per USW type.

Gradually incorporating additional USW types based on their environmental and economic impact leads to the scenario shown in Figure 1 improving emissions reduction. Incorporating glass, paper, and carton further improves the system, while the final addition of organic waste achieves a 62% treatment rate and a 44% increase in avoided CO_2 emissions, though at a significantly higher cost. The proposed matheuristic maintains a computational time consistently below four minutes, demonstrating its efficiency and robustness to problem variations.



(a) Transfer stations' location and collection zones' allocation



(b) Treatment plants' location and transfer stations' allocation

Figure 1: Scenario when plastic, paper, cartons, glass and organic is treated.

Bibliography

[1] Sandoval-Reyes, M., He, R., Semeano, R., and Ferrão, P. Mathematical optimization of waste management systems: Methodological review and perspectives for application. *Waste Management*, 174, 630–645, 2024.

[2] Yu, H., and Solvang, W. D. A multi-objective location-allocation optimization for sustainable management of municipal solid waste. *Environment Systems and Decisions*, 37, 289–308, 2017.

[3] Caramia, M. and Pizzari, E. Bilevel optimization in waste management. *Encyclopedia of Optimization*, 1–7, 2024.

Solution approaches for a fair multi-source capacitated facility location problem

Carlo Filippi [a], **Gianfranco Guastaroba** [a], **Juan-José Salazar-González** [b,*]

[a] University of Brescia, Italy, carlo.filippi@unibs.it, gianfranco.guastaroba@unibs.it
[b] IMAULL, Universidad de La Laguna, Tenerife, Spain, jjsalaza@ull.es
[*] Presenting author.

Keywords: Fairness Location, MILP formulations, Matheuristic approach

Introduction

This article incorporates a fairness measure into the popular Multi-Source Capacitated Facility Location Problem (MSCFLP). The measure is known as conditional β-mean and the resulting problem is termed the Fair MSCFLP (F-MSCFLP). The single-source variant is already addressed in the literature and admits a natural Mixed Integer Linear Programming (MILP) formulation which cannot be adapted to the multi-source variant. This may be why there is no article in the literature on the F-MSCFLP. We present four models for the F-MSCFLP: a bilevel model, a bilinear model, and two MILP models. Computational results show that one of the models outperforms the other three. Still, it fails to solve large-scale instances and therefore we propose and evaluate a new heuristic approach. It is a decomposition approach that iteratively solves a restricted master problem and a subproblem. At each iteration, the master provides an integer or fractional solution to define the subproblem. We describe a procedure to solve this subproblem in linear time on the number of facilities and customers. The optimal dual subproblem solution potentially determines a violated inequality and a missing variable to be added to the master problem. This column-and-row generation is also embedded in a shaking procedure to escape from local optimum potentially. Computational experiments show that the whole approach finds high-quality solutions on F-MSCFLP instances where a sophisticated and updated solver on the new formulations achieves time limits.

The Skip-Stop Problem in Public Transportation

Ricardo Reicherz [a], Anita Schöbel [b,*]

[a] RPTU Kaiserslautern, Germany, reicherz@rhrk.uni-kl.de
[b] Fraunhofer ITWM Kaiserslautern, Germany, anita.schoebel@itwm.fraunhofer.de
[*] Presenting author.

Keywords: Public Transport, Line Planning, Skip Stop, Stop Location

Abstract

One of the early steps in public transportation planning is to design the lines along which service should be offered. Lines are paths in a public transport network which consist of a sequence of stations to be visited one after the other. While there exist many papers on finding the shapes of such lines and on determining their frequencies [4, 3], the problem of deciding about the stations in which a line stops is often neglected.

Consider a line as a sequence of consecutive stations. In order to increase the travel speed of trains or buses in public transport, it may be beneficial to skip some stops on their routes. In such a skip-stop service, a line is divided into two sublines (let's say a blue and a red one) which are operated alternatingly. The stations are also divided into two sets with usually non-empty intersection, a set of blue and a set of red stations. The blue line only stops at blue stations and the red line only stops at red stations. This is hence an idea to speed-up trains in large metropolitan areas [2] but it may also be used for robust planning [1].

Skipping stations, however, has a drawback: There may exist pairs of stations which have no direct connection any more forcing passengers to transfer between the red and the blue line. It may even happen that some passengers have to take detours to travel from their origins to their destinations.

We consider the problem of designing skip-stop patterns from a passenger-oriented point of view. Given a number p of stops to be left out (together in both lines) and a set of origin-destination pairs representing the passengers' demand, we aim at selecting the stations at which the the blue line stops and the stations at which the red line stops, resulting in two *stopping patterns*. We consider several goals:

- minimize the number of transfers of all passengers,
- minimize the number of passengers who will have a detour, or
- minimize the sum of traveling times of the trains.

For all three objectives we provide integer programming formulations and are able to characterize optimal solutions. We then combine these objectives and show which of them are in conflict and which of these goals can be reached simultaneously. The results are illustrated at examples. As an extension, we consider the traveling time of the passengers. This requires

timetables for both, the blue and the red line. Timetabling is an intrinsically hard problem, we sketch first ideas on how it may be tackled in our case.

Bibliography

[1] Cacchiani, V., Qi, J., and Yang, L. Robust optimization models for integrated train stop planning and timetabling with passenger demand uncertainty, *Transportation Research Part B: Methodological*, 136, pp. 1-29, 2020

[2] Freyssa, M., Giesena, R., and Muñoz, J. C. Continuous Approximation for Skip-Stop Operation in Rail Transit, *Procedia- Social and Behavioral Sciences* 80, pp. 186-210, 2013

[3] Schmidt, M. and Schöbel, A. Planning and optimizing transit lines, *Handbook of Transport Modeling* ed. S. N. Parragh and T. V. Woensel arXive, http://arxiv.org/abs/2405.10074, 2024

[4] Schöbel, A. Line planning in public transportation: models and methods, *OR Spectrum* 34(3), pp. 491-510, 2012

On integer programming models for the obnoxious p-median problem

Elisabeth Gaar [a], **Markus Sinnl** [b,*]

[a] University Augsburg, elisabeth.gaar@uni-a.de
[b] Institute of Business Analytics and Technology Transformation/JKU Business School, Johannes Kepler University Linz, Austria, markus.sinnl@jku.at
[*] Presenting author.

Keywords: p-median, mixed-integer programming, obnoxious location

In classical facility location problems, the goal is to locate facilities in such a way that the distance to the customers is minimized according to a given measure. For example, in the p-median problem the goal is to minimize the sum of distances to the nearest open facility. Contrary to that, the goal in the *obnoxious p-median problem (OPM)* is to maximize this distance (see, e.g. [1, 2, 4, 5]). The OPM is thus suitable for locating *undesirable* facilities such as landfills, nuclear power plants or airports.

The OPM can be defined in the following way. Given an integer $p \geq 1$, a set of customers I with $|I| = n$, a set of potential facility locations J with $|J| = m \geq p$ and the distances $d_{ij} \geq 0$ from customer i to the potential facility location j for all $i \in I$ and for all $j \in J$, the obnoxious p-median problem asks for a subset $S \subseteq J$ with $|S| = p$ of potential facility locations to open, such that the sum of the distances between any customer and its closest open facility is maximized, i.e., such that $\sum_{i \in I} \min_{j \in S}\{d_{ij}\}$ is maximized.

In Labbé, Maffioli, Ndiaye and Belotti [4] and the follow-up paper Belotti, Labbé, Maffioli and Ndiaye [1] an integer programming model and many valid inequalities for this model are presented, together with a branch-and-cut algorithm. In Chiang and Lin [2] and the follow-up paper Lin and Chiang [5] four different integer programming models for the OPM are proposed (including the model of [1]). In the computations in [5] only compact models are computationally compared (i.e., only the basic model of [1] is considered, but no branch-and-cut algorithm with additional valid inequalities) and one of the alternative formulations, denoted as *ordered model*, gave the best computational results. We note that [5] did not provide any theoretical comparison between the models except showing that all model the OPM.

In this work we describe new valid inequalities for the model of [1, 4] and also the ordered model of [5]. In particular, we connect existing constraints to model the OPM with the work of Espejo, Marín and Rodríguez-Chía [3], in which different families of *closest assignment constraints (CAC)* for discrete location problems were studied. We show that the OPM falls under the class of problems which can be modeled with such constraints. We specialize families of CAC to the OPM to arrive at new valid inequalities, and also extend other existing families of valid inequalities.

We give theoretical results on the strength of the new valid inequalities and also compare the strength (in terms of value of the linear programming-relaxation) of both exiting models from literature. Interestingly, we can show that the ordered model, which computationally worked better in [5] is actually weaker compared to the basic model of [1, 4]. Only after adding some of our new valid inequalities to the ordered model both have the same strength. Based on our theoretical results we implemented two branch-and-cut algorithms. We conduct a computational study on instances also considered in [5] to assess the impact of our inequalities. Interestingly, we are not able to reproduce the results of [5], in particular, the ordered model is not the one with the best performance in our computational study. This could potentially be attributed to the fact that we used a different integer programming solver, i.e., [5] used a relatively old version of Gurobi which was not available to us. Unfortunately, [5] does only provide the runtime in their results and no other information like root bound or number of branch-and-bound nodes which could help to better analyze the situation. On the other hand, our computational results are consistent with our obtained theoretical results regarding the strength of the linear programming relaxations of the different models.

Bibliography

[1] Belotti, P., Labbé, M., Maffioli, F., and Ndiaye, M. A branch-and-cut method for the obnoxious p-median problem. *4OR*, 5(4), 299–314, 2007.

[2] Chiang, Y.I. and Lin, C.C. Compact model for the obnoxious p-median problem. *American Journal of Operations Research*, 7(06), 348, 2017.

[3] Espejo, I., Marín, A., and Rodríguez-Chía, A.M. Closest assignment constraints in discrete location problems. *European Journal of Operational Research*, 219(1), 49–58, 2012.

[4] Labbé, M., Maffioli, F., Ndiaye, M., and Belotti, P. Obnoxious p-median problems: valid inequalities and a branch-and-cut approach. *The OR Peripatetic Post-Graduate Programme*, 26–29, 2001.

[5] Lin, C.C. and Chiang, Y.I. Alternative formulations for the obnoxious p-median problem. *Discrete Applied Mathematics* 289, 366–373, 2021.

Location of services in urban areas using presence data and GIS information

Francesco Bianchi [a], Giovanni Felici [a,b], Giuseppe Stecca [a,b,*]

[a] CNR IASI - Institute for Systems Analysis and Computer Science "Antonio Ruberti", Italy
francesco.bianchi@iasi.cnr.it, giovanni.felici@iasi.cnr.it,
giuseppe.stecca@iasi.cnr.it
[b] CNR CISC - Interdepartmental Centre for Cities Science, Italy
[*] Presenting author.

Keywords: Location, Presence Data, Urban Planning

Introduction and literature review

Successful planning and development of cities requires that services offered to citizens and tourists adapt to evolving trends in the best possible way. Emergent digital technology and advanced location based data analytics can be successfully exploited for supporting the urban planning process in this direction.

In this work we propose a methodology to integrate presence data from cellular phones with Points of Interest (PoIs) retrieved by open GIS (Geographic Information Systems) and solve the location problem while considering data imputed on the city graph. The application is developed within different projects applied to Italian cities, and results presented here focus on the city of Matera, in south Italy.

Location based services provided a huge push on developing methods useful to analyze and synthesize the way people use urban areas or mobility services. The review in [3], describes different technologies and different applications of using data for occupancy profiles. The data used in our method are provided by a telecom company which are able to identify presence of mobile telecommunication devices in a grid of 150X150m tiles every 15 minutes, differentiated by user profile. The possibility to integrate these data to forecast mobility behavior of people but also occupancy has been deepened in [1]. The paper presents the urban digital twin concept where real time data are used in conjunction with GIS information to develop decision support system applications, such as orienteering services. Classical location models such as *p-median* or *p-center* can be exploited to locate public utility or emergency services accurately based on sensor data, in urban environments as detailed in the review of Farahani et al. [2].

Model development and conclusions

We use the GIS information and the cellular presence data in order to enrich the underlying road graph of a city. As shown in Figure 1, it is possible to have several type PoIs, to be associated to the tiles of the presence data provided by the telecom company. Moreover tiles and its information are imputed to road graph.

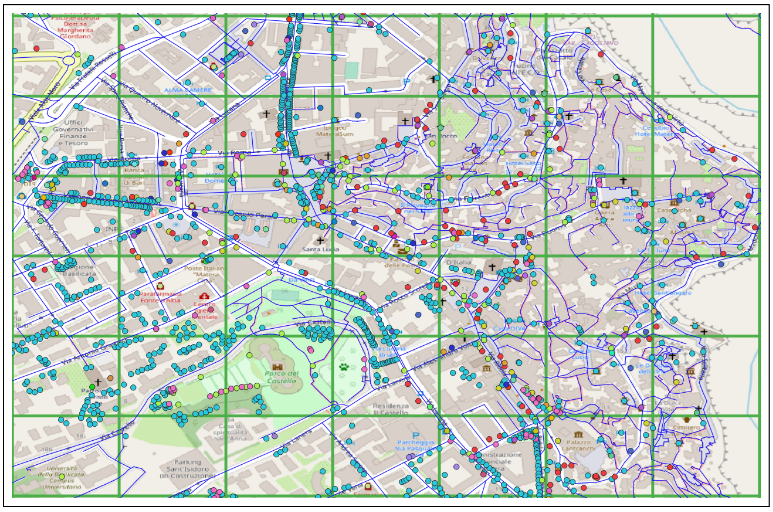


Figure 1: PoIs, road graph and presence tiles in the studied city.

The model aims to maximize the expected utility function defined as $\sum_{e\in E,h\in H,t\in T} Uy^e_{ht}$ for opening services in the urban area. Given an edge $e \in E$ of the road Graph $G = V, E$, we define the discrete variable y^e_{ht} equal to the number of services or (PoIs) of type h located on the edge e, with operational time in timewindow t. The utility depends in particular from other PoIs already located in each edge and nearby, by the presence approximating the potential demand, and the walking distance from the edge.
Together with synthetic data, we describe the application of the model to an Italian city, considering location of different facilities, such as points for serving people during peak events, mobile stations for electric bicycles, public services for residents and commuters considering time window requirements.

Acknowledgements

This work is partially supported by the project "House of emerging technologies of Matera" (CTEMT) funded by the Ministry of Economic Development of Italy, CUP I14E20000020001, and and CNR DIT.AD106.097 project UISH - Urban Intelligence Science Hub, CUP B51B1200430001.

Bibliography

[1] De Benedictis, R., Cesta, A., Pellegrini, R., Diez, M., Pinto, D. M., Ventura, P. Stecca, G., Felici, G., Scalas, A., and Mortara, M. *et al.* Digital twins for intelligent cities: the case study of Matera. *Journal of Reliable Intelligent Environments*, vol. 11, no. 1, p. 6, 2025.

[2] Farahani, R. Z., Fallah, S., Ruiz, R., Hosseini, S., and Asgari, N. "OR models in urban service facility location: A critical review of applications and future developments." *European Journal of Operational Research*, vol. 276, no. 1, pp. 1–27, 2019, Elsevier.

[3] Nejadshamsi, S., Eicker, U., Wang, C., and Bentahar, J. "Data sources and approaches for building occupancy profiles at the urban scale—A review." *Building and Environment*, vol. 238, p. 110375, 2023, Elsevier.

The Clustered Multimode Set Covering Problem

Andrea Mancuso [a], Antonio Manuel Rodríguez-Chía [b], Francisco Saldanha-da-Gama [c], Claudio Sterle [d,*]

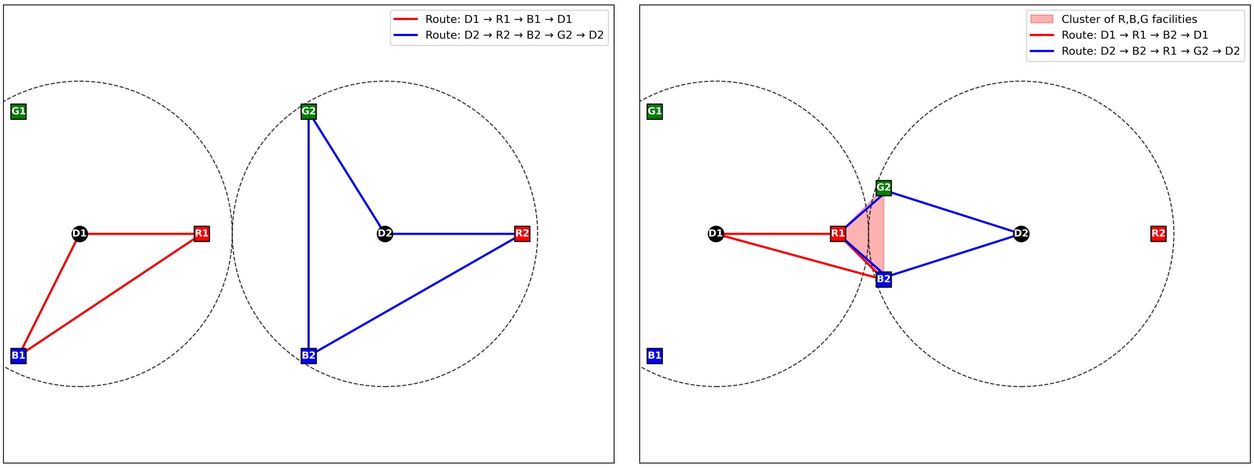
[a] Department of Political Sciences, University of Naples Federico II, Via L. Rodinó 22, 80138, Naples, Italy.
[b] Departamento de Estadística e Investigación Operativa, Universidad de Cádiz, Facultad de Ciencias, 11510, Puerto Real (Cádiz), Spain.
[c] Sheffield University Management School, S10 1FL, Sheffield, United Kingdom.
[d] Department of Electrical Engineering and Information Technology, University of Naples Federico II, Via Claudio 21, 80125, Naples, Italy.
[*] Presenting author.

Keywords: Facility Location, Set Covering, Clustering

Classical covering problems in operations research aim to determine the optimal placement of facilities to effectively serve demand points while minimizing costs or maximizing coverage. Prominent models, such as the Set Covering Location Problem (SCLP) [4] and the Maximal Covering Location Problem (MCLP) [1], address these objectives by either minimizing the number of facilities needed to cover all demand points or maximizing the number of covered weighted demand points given a fixed number of facilities, respectively. However, these problems assume a single type of facility, ensuring each demand point is covered within a predefined radius. While suitable for problems requiring a single type of service, this assumption neglects real-world scenarios where multiple facility types may be necessary. For instance, multiple sensors may be needed to cover an area for comprehensive environmental data integration. Additionally, if an individual must visit several service facilities within a single trip, the feasibility of such multi-destination travel depends on the spatial arrangement of those multiple types of facilities.

This introduces an additional challenge: different facility types may compete for the same locations, preventing the problem from being decomposed into separate covering problems for each facility type. The Multimode Covering Location Problem (MCLP) [2] addresses this issue by integrating the coexistence of multiple facility types. Moreover, it accounts for additional complexities in coverage requirements. Indeed, it is not enough to ensure that each demand point is served by one facility of each type; it is equally important to consider the spatial relationships among facilities. Poorly coordinated placements may maximize individual accessibility but fail to facilitate efficient trip chaining, emphasizing the need for compact and strategically coordinated facility placement.

To address this challenge, we introduce the Clustered Multimode Set Covering Problem (CMSCP), an extension of the SCLP designed to ensure demand point coverage by multiple facility types while promoting spatial clustering to support multi-purpose trips. Specifically, we propose an Integer Linear Programming (ILP) formulation that optimizes the number of located facilities while enhancing compactness through cluster formation. Each cluster consists of one facility of each type, with one facility serving as the centroid. Additionally, facilities can belong to multiple clusters. Cluster compactness is evaluated by minimizing the sum of distances between each facility and its centroid. Along with the model, we developed a branch-and-cut algorithm to efficiently solve large instances. Experimental results demonstrate the effectiveness of this approach in handling real-world problem sizes.



(a) Multi-destination trips without cluster coverage. (b) Multi-destination trips with cluster coverage.

Figure 1: Illustration of the two-level coverage concept.

For clarity, the benefits of the CMSCP can be illustrated through a simple example, Figure 1 compares two facility placement strategies. In Figure 1a, the red line represents the demand node $D1$ visiting two facilities ($R1$ and $B1$) within its coverage radius, while the blue line shows $D2$ accessing three ($R2$, $B2$, and $G2$). In contrast, Figure 1b illustrates a more efficient clustered strategy: $D1$ now visits $R1$ and $B2$, while $D2$ reaches $B2$, $R1$, and $G2$. Although some facilities lie outside their original coverage radii, the compact cluster formed by $R1$, $B2$, and $G2$ (highlighted in red) ensures that once any facility in the cluster is reached, the others are easily accessible, minimizing additional travel. It is clear that this approach balances flexibility for both single- and multi-destination trips. Individuals seeking a single service can visit their nearest facility, while those needing multiple services benefit from reduced travel.

Bibliography

[1] Church, R., and ReVelle, C. The maximal covering location problem. *Papers in Regional Science*, 32(1):101–118, 1974.

[2] Colombo, F., Cordone, R., and Lulli, G. The multimode covering location problem. *Computers & Operations Research*, 67:25–33, 2016.

[3] Laporte, G., Nickel, S., and Saldanha-da-Gama, F. *Introduction to location science*. Springer, 2019.

[4] Toregas, C., Swain, R., ReVelle, C., and Bergman, L. The location of emergency service facilities. *Operations Research*, 19(6):1363–1373, 1971.

New generalized Stackelberg solutions in Security Games

Lina Mallozzi [a], Justo Puerto [b], Francisco Temprano [b,*]

[a] University of Naples Federico II, mallozzi@unina.it
[b] University of Seville, puerto@us.es, ftgarcia@us.es
[*] Presenting author.

Keywords: Bilevel optimization, Game theory, Stackelberg equilibrium

Introduction

Security games is a classic problem in Game theory, where two different player roles can be distinguished, attackers and defenders. Indeed, the original problem presented by [1] is defined as a two-player game between a defender and an attacker. Each of the players will make a decision based on its role and its profit/pay-off function in the Security game.
Specifically, we have analyzed them as Stackelberg games where the defenders play the leader role and attackers the follower role. The case where there is just one defender and a set of possible attackers to face is deeply studied and analyzed in [2].
In this talk, we have considered two variants of the above problem. The first one consists of multiple defenders that can cooperate to increase their benefits, and the second one contemplates the possibility of limiting the attacker decision space as a decision of the defenders. The solution structures of these new problems are analyzed and compared with the ones of the original problems.

Bibliography

[1] Kiekintveld, C. and Jain, M. and Tsai, J., and Pita, J. and Ordóñez, F., and Tambe, M. Computing optimal randomized resource allocations for massive security games. *Proceedings of The 8th International Conference on Autonomous Agents and Multiagent Systems - Volume 1*, 689–696, 2009.

[2] Casorrán, C., Fortz, B., Labbé M., and Ordóñez, F. A study of general and security Stackelberg game formulations. *European Journal of Operational Research*, 278(3), 855-868, 2019.

Order then optimize: a flexible modeling framework in Location Science

Victor Blanco [a], Miguel A. Pozo [b], Justo Puerto [b], Alberto Torrejon [b,*]

[a] University of Granada, vblanco@ugr.es
[b] University of Sevilla, mpozo@us.es, puerto@us.es, atorrejon@us.es
[*] Presenting author.

Keywords: Robust measures, combinatorial problems, quadratic programming, ordered optimization, bilevel problems

Optimization in decision-making is fundamentally driven by the objective function, which can vary depending on the context, ranging from measures of position, dispersion or shape of the distribution to measures of risk, fairness, robustness, or envy, among others. In this work, we introduce a flexible modeling framework based on linear and mixed-integer mathematical programming, designed to accommodate a broad spectrum of optimization criteria in combinatorial problems. We focus on its application to facility location problems, see [1] or [2], while remarking its adaptability to other domains, such as linear regression, see [3]. To this end, we present novel approaches leveraging ordered and bilevel optimization techniques, supported by computational studies which outline the performance of our methods. Our framework allows for the integration of problem-specific constraints and preferences, making it a versatile tool for decision-makers in various fields. Additionally, we explore theoretical properties of the proposed models and discuss their computational complexity. The results highlight the potential of our approach to improve solution quality and interpretability across multiple optimization settings.

Bibliography

[1] Ljubic, I., and Pozo, M. A., and Puerto, J., and, Torrejon, A. Benders decomposition for the discrete ordered median problem. *European Journal of Operational Research*, 317(3), 858-874, 2024 (https://doi.org/10.1016/j.ejor.2024.04.030)

[2] Pozo, M. A., and Puerto, J., and, Torrejon, A. The Ordered Median Tree Location Problem. *Computers and Operations Research*, 169, 106746, 2024 (https://doi.org/10.1016/j.cor.2024.106746).

[3] Puerto, J., and, Torrejon, A. A fresh view on Least Quantile of Squares Regression based on new optimization approaches. *arXiv*, (https://doi.org/10.48550/arXiv.2410.17793)

Managing Involuntary Migration

Melek Tuncel [a,*], **Bahar Y. Kara** [b]

[a] Department of Industrial Engineering, Bilkent University, Turkey,
melek.tuncel@bilkent.edu.tr
[b] Department of Industrial Engineering, Bilkent University, Turkey,
bkara@bilkent.edu.tr

Keywords: migration, push and pull factors

Introduction

The choice of destination in migration processes is shaped by a complex interplay of push and pull factors. Push factors drive individuals away from their current locations, while pull factors attract them toward destinations that promise to meet their needs and aspirations. The relative significance of these factors varies across different contexts and migration scenarios. This paper seeks to systematically identify and categorize the key push and pull factors influencing post-disaster migration, drawing from existing case studies, conceptual frameworks, and empirical data across a range of disaster types. This study aims to enhance theoretical understanding of the drivers behind migratory movements in post-disaster settings through synthesizing insights from diverse sources. By providing an organized structure on push and pull factors, the paper aims to expand and strengthen the framework for future research on migration.

Scheduled Service Network Design for Integrated Passenger and Freight Transportation

Krissada Tundulyasaree [a,*], Emrah Demir [b], Rolf N. van Lieshout [a], Layla Martin [a] Tom Van Woensel [a]

[a] Operations, Planning, Accounting and Control, Eindhoven University of Technology,
k.tundulyasaree@tue.nl, r.n.v.lieshout@tue.nl, l.martin@tue.nl,
t.v.woesel@tue.nl

[b] Logistics & Operations Management Section, Cardiff Business School, Cardiff University
demire@cardiff.uk

[*] Presenting author.

Keywords: Service network design, ALNS, Hub location

Introduction

With increasing demand, urban freight transport contributes greatly to negative impacts on cities, including air pollution, noise pollution, congestion, and accidents. A sustainable solution is the modal shift from road transport to cleaner modes such as rail and waterways. To facilitate this shift, it is necessary to redesign logistics networks and equip selected locations with transshipment facilities. Although this shift can mitigate externalities, it can also prolong transportation time due to handling delays. The redesigned network, therefore, must balance environmental goals with feasible transportation time. In addition, typical government policies, such as restrictions on truck transport times, can be further addressed by storing goods at hubs until delivery. Given these challenges, we introduce a scheduled service network design problem with hub selection that considers time-dependent demand, service capacity, and hub capacity.

Problem Statement

The transportation authority aims to mitigate the negative impacts of road freight transport by establishing freight hubs at train stations, thus promoting a modal shift to urban rail systems such as metro and tram services. Given the fixed schedules of the train services and the timed requests, freight forwarders must accurately time the deliveries to synchronize the truck and train operations. Establishing freight hubs at railway stations requires significant investment in equipment upgrades and storage space allocation to handle freight flows. Consequently, the authority faces the challenge of routing freight flows through a variable network structure, where only certain stations can be designated as freight hubs due to a limited budget.
Each potential freight request includes demands, origins, destinations, and specific ready and due time. For last-mile logistics, the planning horizon is short-term (e.g., one day). During this period, the demands and transport services (road and railway) are assumed to be known. The travel times between locations by road or rail are known in the existing transport network. Furthermore, trucks are assumed to be available for any origin-destination pair at any time,

considering all carrier companies in the area. The station locations and service schedules for the railway network are known, including departure and arrival times. Train services are assumed to have sufficient capacity for freight transportation, with non-restrictive capacity for each service.

All requests must be fulfilled through either direct road transport or integrated road and rail transport. For rail transport, freight can only enter and exit the system at designated hub stations. In addition, the storage space at each station is limited. Given a limited budget, the authority can only open a certain number of hubs. They must route freight flows by scheduling trucks, selecting hub stations, and choosing train services to distribute the negative impacts of freight transport throughout the network.

Methodology

We formulate this problem as a scheduled service network design problem with hub selection to explore the impacts of network design on flow paths. The static version of the problem was first proposed by Yoon and Current [1]. The time-dependent problem is further explored by [2, 3] to consider the time related to demands. However, neither of them considers the service selection and the hub capacity simultaneously. Our objective is to minimize the total transportation cost, which varies according to the freight load, the number of vehicles assigned and the cost of using hubs. Given the complexity of the problem, we solve small instances adapted from the Service Network Design problem in the literature to optimality. To derive insights for real-world applications, we develop a matheuristic combining Adaptive Large Neighborhood Search algorithm with solving a minimum cost flow problem. We introduce operators at the node and arc levels and obtain the optimal flow by solving minimum-cost flow problems. We explore the trade-off between the redistribution of externalities and the increased transportation cost. In addition, we investigate the relation between the number of hubs, logistic costs, and the amount of negative externalities. Finally, we conduct a sensitivity analysis of how station selection is affected by demand.

Bibliography

[1] Yoon, M. and Current, J. The hub location and network design problem with fixed and variable arc costs: Formulation and dual-based solution heuristic. *Journal of the Operational Research Society*, 59(1), 80-89, 2008.

[2] Elbert, R., Rentschler, J., and Schwarz, J. Combined Hub Location and Service Network Design Problem: A Case Study for an Intermodal Rail Operator and Structural Analysis. *Transportation Research Record*, 2677(1), 730-740, 2023.

[3] Giusti, R., Manerba, D., Crainic T. G., and Tadei, R. The synchronized multi-commodity multi-service Transshipment-Hub Location Problem with cyclic schedules. *Computers and Operations Research*, 158, 92-106, 2023.

Team Formation and Debris Assignment for Post-Disaster Search and Rescue Operations: An Operational Research Perspective

Egehan Uğraş [*], Zehranaz Dönmez Varol , Bahar Y. Kara

Deparment of Industrial Engineering, Bilkent University, Ankara, Turkey
egehan.ugras@ug.bilkent.edu.tr, zehranaz.donmez@bilkent.edu.tr, bkara@bilkent.edu.tr
[*] Presenting author.

Keywords: Search and Rescue, Team Formation, Debris Assignment, Humanitarian Logistics

Introduction

Search and Rescue (SAR) operations play a vital role in disaster response after large-scale events like earthquakes, where rapid intervention can save lives. The effectiveness of these operations relies on team management, coordination and efficient decision-making [1]. SAR operations are classified into distinct types based on their operational environment and Urban Search and Rescue (USAR) teams specialize in extricating individuals from collapsed structures. USAR teams are typically classified based on their operational capabilities. International Search and Rescue Advisory Group (INSARAG) categorize USAR teams into three levels: Light, Medium, and Heavy. Staff requirements for these teams offered by INSARAG can be seen in Table 1. Light USAR teams possess the capability to conduct surface search and rescue operations in the immediate aftermath of a disaster. Medium USAR teams have enhanced capabilities, including technical search and rescue operations, and are equipped to handle more complex scenarios with the capacity to sustain 24-hour operations at a single site for up to seven days. Heavy USAR teams are the most advanced ones, with the capacity to conduct complex technical search and rescue operations and equipped to handle large-scale structural collapses and operate in multiple locations simultaneously for up to ten consecutive days. These teams include a diverse set of specialists which makes them essential for complex disaster scenarios. Effective SAR operations also rely on a structured response framework, which involves sectorization of disaster area and coordination among multiple teams. The sectorization approach divides disaster zones into manageable sectors, allowing for efficient allocation of SAR teams. This ensures that teams operate within their expertise level and helps reducing response time [2].

Our study presents a mathematical model for the formation and assignment of SAR teams. The model assigns volunteers to teams, forms teams with appropriate expertise, and allocates them to debris sites while considering operational constraints. It takes as input the number of available volunteers, leaders, team types and roles required within a SAR team. The model incorporates debris site requirements and the feasibility of assigning specific team types to different debris locations. A key feature of our approach is the introduction of an

additional team category between light and medium teams, designed to improve flexibility in SAR operations. This new team type allows for partially completed teams that can either be combined with international teams for full functionality or provide critical information on missing personnel needed to meet medium team requirements. The model identifies gaps in staffing and allows this information to be shared with professional chambers, NGOs, or relevant organizations to recruit the necessary personnel or adjust assignments as new volunteers arrive. By incorporating this adaptive team structure, our model enhances coordination in disaster response, ensuring that SAR efforts can be dynamically adjusted based on resource availability. Another feature of the model is adaptability to different disaster scenarios. Each earthquake presents unique challenges in terms of scale, severity, and timeline, requiring different types and compositions of SAR teams. The model accounts for these variations, making it applicable across different earthquake scenarios. To demonstrate its adaptability, we have applied the model to different disaster scenarios, analyzing how team composition and assignment strategies change based on earthquake characteristics. The model's output provides a configuration of teams, leader assignments, and debris site coverage. This approach not only enhances operational effectiveness in large-scale disaster scenarios but also supports collaborative SAR efforts between national and international response units.
Our study differentiates from the existing literature by focusing on the integration of classification and accreditation systems into the team formation process and assigning these teams to debris. Our approach incorporates real-life experiences and challenges faced during SAR operations. By aligning theoretical frameworks with insights from field, we provide a perspective that bridges the gap between theory and practice by offering different disaster scenarios.

Table 1: Number of suggested staff for teams by INSARAG

Component	Light	Medium	Heavy
Management	1	8	11
Search and Rescue	10	24	40
Medical	2	4	6
Logistics	4	6	6
Total	17	42	63

Bibliography

[1] Andreassen, N., Borch, O. J., and Sydnes, A. K. Information sharing and emergency response coordination. *Safety Science*, 130, 2020.

[2] INSARAG. INSARAG Guidelines Volume II: Preparedness and Response https://insarag.org/wp-content/uploads/2021/09/INSARAG20Guidelines20Vol20II2C20Man20B.pdf, 2020.

A Time Space Network Model for a Truck and Drones Delivery System with Battery Recharging and Variable Speeds

Lavinia Amorosi [a], **Paolo Dell'Olmo** [a], **Justo Puerto** [b], **Carlos Valverde** [b,*]

[a] Department of Statistical Sciences, Sapienza University of Rome, Italy,
lavinia.amorosi@uniroma1.it, paolo.dellolmo@uniroma1.it,
[b] Department of Statistical Sciences and Operational Research, University of Seville, Spain,
puerto@us.es, cvalverde@us.es
[*] Presenting author.

Keywords: Delivery system, Time-space network, Hybrid Fleets, Mixed-Integer Quadratic Programming, UAVs, Matheuristic Algorithm

Introduction

We present a multiperiod mixed-integer quadratic programming formulation based on a time-space network for a delivery problem with a mothership and a fleet of drones. The system is supposed to operate in European cities with high congestion, very narrow streets not reachable by trucks, no parking areas, but where customers demand is located. The mothership can stop only on a set of locations where parking is possible which are different from the customers' locations. During mothership stops, deliveries are performed by drones that can fly at different speeds. The proposed formulation integrates the routing of the mothership and scheduling of the drones problems, including also the charging cycles of drone batteries. The optimization is performed by minimizing the total energy consumption (proportional to the drones and truck traveled distances) and by maximizing the number of served customers. The formulation is also exploited to design an effective matheuristic algorithm. A case study related to the city of Rome with up to 200 customers is presented to validate the model and illustrate the solutions structure. Extensive computational results on a large testbed of artificial instances, up to 200 customers, are reported both for the formulation and the matheuristic algorithm.

Enhancing Fairness in Emergency Medical Service: Single- and Bi-Objective Model Formulations

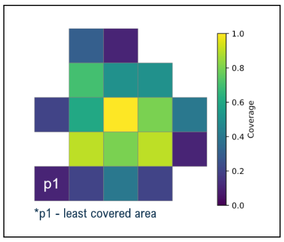
Isabel Wiemer *, **Jutta Geldermann**

Chair of Business Administration and Production Management, University Duisburg-Essen, Germany, isabel.wiemer@uni-due.de, jutta.geldermann@uni-due.de
* Presenting author.

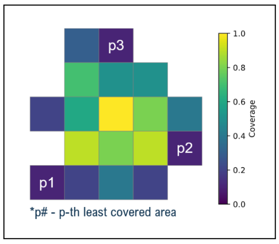
Keywords: Location Planning, Emergency Medical Service, Fairness

Abstract

The primary goal of emergency medical service (EMS) is to respond quickly and efficiently to all emergencies within the considered area. However, especially in areas with a heterogeneous demand distribution like urban, mixed, and rural areas, the level of coverage can vary widely. To reduce inequalities in coverage, many approaches take into account fairness as model objective when planning EMS locations. One possibility is to explicitly address the least-covered area by maximizing its expected coverage [3], see Figure 1(a). Although the coverage levels of the second, third, and other poorly covered areas are mostly only slightly better compared to the worst-covered area, they are not directly addressed. Therefore, we propose explicitly considering not only the worst-covered area but also the second, third, and subsequent least-covered areas. Our goal is to enhance the average coverage level across the set p of worst-covered areas, as illustrated in Figure 1(b).



(a) Maximizing coverage of least covered area.

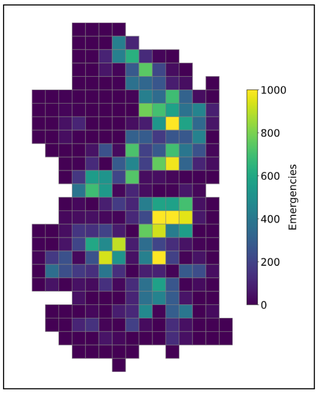


(b) Maximizing average coverage of set p least covered areas.

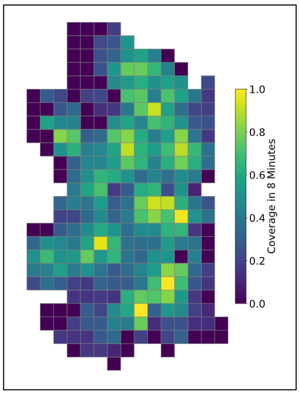
Figure 1: Illustration of fairness objective.

To that end, we introduce a novel fairness objective and formulate a single-objective model. Additionally, we combine the proposed fairness objective with expected coverage to a bi-objective model, utilizing the epsilon constraint method [2]. Both models are based on an extension of the Maximum Expected Covering Location Model (MEXCLP) [1], which accounts for fractional coverage [5]. With fractional coverage, a specific probability is assigned to each combination of site and demand area, representing the probability that an ambulance from the site will respond to an emergency call in the area within the designated response time [4].

To evaluate the applicability of our proposed fairness objective, we conduct a real-world case study for the city of Duisburg, Germany, with historical emergency data from Duisburg's EMS providers, see Figure 2(a). We analyze various sets p of the worst-covered areas and different epsilon values to evaluate the individual coverage levels as well as overall expected coverage. Preliminary results indicate that our proposed fairness objective enhances the average coverage of the set p worst-covered areas in Duisburg while maintaining a high level of overall efficiency, as shown in Figure 2(b).



(a) Emergencies in the year 2022



(b) Expected coverage for bi-objective model

Figure 2: Model application to the city of Duisburg, Germany

Directly comparing the single-objective and bi-objective model, we find that using the bi-objective approach is not always necessary. Increasing the size of the set p sufficiently can achieve similar effects to when balancing efficiency and fairness within the bi-objective model. This suggests that fairness can be improved without significantly compromising overall coverage, even without a bi-objective formulation. Therefore, we find that the proposed fairness objective can be a valuable tool to integrate both coverage and fairness within a unified framework.

Bibliography

[1] Daskin, M. A maximum expected covering location model: formulation, properties and heuristic solution. *Transportation Science*, 17, 48-70, 1983.

[2] Ehrgott, M. Multicriteria optimization. *Springer*, 2nd edition, 2005.

[3] Grot, M., Nagel, L., Becker, T., Fiebrandt, P. M., and Werners, B. Fairness or efficiency-Managing this conflict in emergency medical services location planning. *Computers and Industrial Engineering*, 172, 108664, 2022.

[4] Karasakal, O. and Karasakal, E. K. A maximal covering location model in the presence of partial coverage. *Computers and Operations Research*, 31, 1515-1526, 2004.

[5] van den Berg, P. L., Kommer, G. J., and Zuzáková, B. Linear formulation for the Maximum Expected Coverage Location Model with fractional coverage. *Operations research for Health Care*, 8, 33-41, 2016.

A combinatorial branch-and-bound algorithm for the single-source capacitated facility location problem with strict customer preferences

Christina Büsing, Felix Engelhardt, Sophia Wrede *

Combinatorial Optimization, RWTH Aachen University, Ahornstraße 55, 52074 Aachen, Germany, buesing@combi.rwth-aachen.de, engelhardt@combi.rwth-aachen.de, wredeengelhardt@combi.rwth-aachen.de

* Presenting author.

Keywords: discrete location, customer preferences, branch-and-bound

In the classical *single-source capacitated facility location problem* (CFLP), a set of facilities needs to be chosen in order to cover the demand of customers. Customers are assigned to any open facility such that the capacity of the facility is not exceeded and the total cost consisting of opening and assignment cost is minimised. However, in many real-world applications customers are not willing to travel to any open facility assigned to them but want to select an open facility according to their preferences [1]. Such deviations can turn feasible solutions for the CFLP infeasible. The *single-source capacitated facility location problem with customer preferences* (CFLP-CP) takes this behaviour into account by assigning each customer to their most preferred open facility. Determining feasibility for both the CFLP and CFLP-CP is strongly NP-complete. Preference constraints, however, imply certain combinatorial structures which do not occur in the classical CFLP. These implied structures render some previously NP-complete special cases of the CFLP easy to solve [2].

In this talk, we study the case in which each customer has a strict preference ordering. We call this problem *CFLP-SCP* where *S* indicates strict customer preferences. First, we discuss an algorithm which determines feasibility of the CFLP-SCP in polynomial time. Next, we outline a combinatorial branch-and-bound algorithm utilising the previous algorithm to derive upper bounds. Besides upper and lower bounds, we also discuss steps to keep the branching tree small. Finally, we evaluate the performance of our branch-and-bound algorithm for two preference types in a computational study.

Bibliography

[1] Polino, S., Camacho-Vallejo, J.-F., and Villegas, J. G. A facility location problem for extracurricular workshop planning: bi-level model and metaheuristics. Intl. Trans. in Op. Res. 31 (6), pages 4025 - 4067, 2024.

[2] Büsing, C., Gersing, T., and Wrede, S. Analysing the complexity of facility location problems with capacities, revenues, and closest assignments, Proceedings of the 10th International Network Optimization Conference (INOC), Aachen, Germany, June 7–10, pages 81 – 86, 2022.

Deep-learning Aided Crowdshipping Network Design with External Delivery Vehicles

Ramazan Çevik , Ali Şardağ , Barış Yıldız *
Department of Industrial Engineering, Koç University, Sariyer, Istanbul, Turkiye
rcevik18@ku.edu.tr, asardag16@ku.edu.tr, byildiz@ku.edu.tr
* Presenting author.

Keywords: Crowdshipping, Dynamic Programming, Surrogate models

Introduction

Crowdshipping is an alternative delivery method wherein ordinary members of the society take part in delivery processes by agreeing to carry a package along their pre-determined trips in exchange for a small compensation. Crowdshipping has been garnering increasing attention thanks to its economical and environmental benefits, as it can help reduce traffic and related emissions while completing delivery operations cheaper. However, crowdshipper arrivals are sporadic by nature; which hinders the effectiveness and reliability of such systems along routes that experience particularly high amounts of package flow. The aim of this study is to design a crowdshipping network, augmented with dedicated delivery vehicles along specific routes to aid in the delivery of packages in large volumes; thereby assisting crowdshipping systems and enhancing their usability in heterogeneous demand networks.

Problem Setting

We consider a delivery network composed of service points, e.g. parcel lockers or stores, where packages can be picked up and dropped off. A package can be shipped between any two points through the network, and can be delivered either by a crowdshipper (availability of which is stochastic), or through a professional delivery service (which is assumed to be available instantaneously). Finally, we allow transshipments; that is, during delivery, a package can be sent to an intermediate point instead of being directly delivered to its final destination. We intend to supplement this crowdshipper delivery network with extraneous delivery vehicles; which are vehicles that are scheduled to be traversing a certain route at a given time of the day, and can deliver packages between successive service points along their routes. This should enable the crowdshipper network to be more robust against package build-up.

Problem Definition & Solution Methodology

We model the problem on a time-extended representation of the delivery network, GV, A where V denotes the set of time-copies of the service points of the delivery network, and the arc set A connects two points in the network with respect to their travel time. Our aim is to find the optimum locations for the dedicated delivery lines which will minimize the expected joint cost of crowdshipped delivery and vehicle operations.

For a given set of dedicated delivery lines; we can find the minimum expected cost of crowdshipping operations by solving a stochastic dynamic program. We formulate this

program over a directed acyclic graph and show that this structure can be leveraged to design an efficient solution for it. We further show that our optimality equations cannot offer convexity guarantees, but can still be solved analytically to find the global minimum.
We can thus find the expected delivery costs for a given location set. The next question is to find the "best" location set that minimizes the total expected delivery and operational costs. To this end, we make use of a surrogate model, which we use to predict the expected crowdshipping delivery cost for a given set of vehicle locations; and jointly optimize this surrogate with location routing constraints. Our surrogate model is a feed-forward neural network (FNN) with two hidden layers and the activation function $\sigma x = x^2$. We train our model on a randomly generated set of location configurations, which is constructed by random selection among a subset of "promising" locations; that is, routes which exhibit a high package traffic in our data.
We show that the deep learning model we picked can be embedded into a MINLP model using appropriate convexification and linearization methods under mild assumptions; and present a mixed-integer quadratic formulation of the above problem which can be solved efficiently.
Preliminary results of the vehicle locating procedure indicate promising outcomes in algoritmic performance and potential savings of the proposed enhancement to the dynamic crowdshipping model, accompanied by the practical flexibility of the combined cost modeling.

Tight lower bounds for Multiple Allocation HLPs from two-index supermodular inequalities

Elena Fernández, Nicolás Zerega *

Departamento de Estadística e Investigación Operativa, Universidad de Cádiz, Spain,
elena.fernandez@uca.es, nicolas.zerega@uca.es
* Presenting author.

Keywords: Hub-location, Supermodular functions, Network design, MIP

Abstract

Hub Location Problems (HLPs) have been extensively studied over the years due to their relevance and applications in facility location and network design by combining both, strategic and operational decisions. Our research focuses on tight formulations for Multiple Allocation HLPs with setup costs for both hubs and inter-hub links, using supermodular set inequalities. Building on the $\mathcal{O}n^2$ formulation introduced in [1], we propose significant enhancements that strengthen the linear relaxation and improve computational efficiency. Specifically, we propose a reinforced expression of the supermodular inequalities of [1], which reduces the LP relaxation gap of the original formulation by at least 20% for data instances of up to 80 nodes. The obtained LP bounds are slightly weaker than those produced by classical formulations with 4-index variables. These improvements enable the solution of previously challenging instances, while using available solvers.
The generic nature of the presented reinforcements can be adapted to the p-Hub location context. Results obtained so far, demonstrate that incorporating fairly straightforward inequalities produces near-optimal solutions at the root node, for instances with up to 80 nodes.
Our contributions include: (1) a reinforced supermodular formulation for Multiple Allocation HLPs with 2-index decision variables only, (2) the adaptation to the p-Hub context, (3) improved valid inequalities that tighten the LP relaxation in both contexts, and (4) computational results demonstrating the effectiveness of our approach.

Bibliography

[1] Contreras, I. and Fernandez, E. Hub Location as the Minimization of a Supermodular Set Function. *Operations Research*, 62(3), 557-570, 2014.

Author Index

H

I

J

K

L

M

R

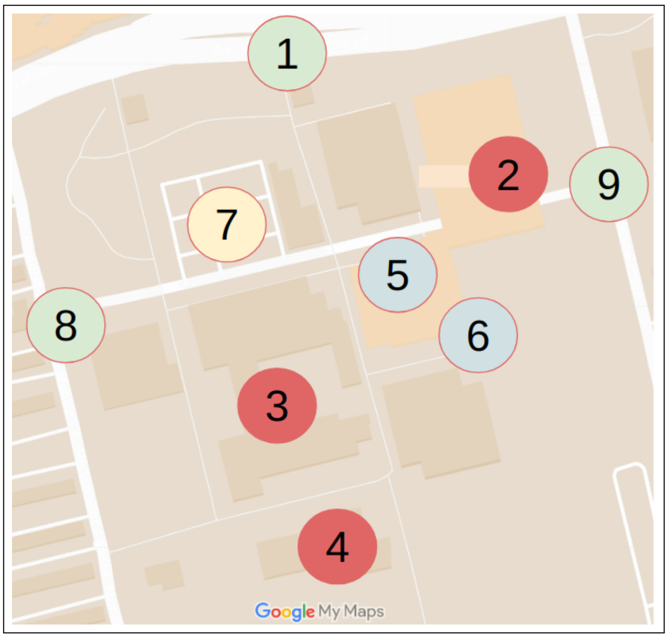
S

Useful Information

Venues

The meeting will be held at Universidad de Cádiz - Campus de Jerez in the city of Jerez de la Frontera (Av. de la Universidad, s/n, 11405 Jerez). The registration, opening and the final EWGLA session will take place in the Office and Seminar Building (Edificio de Despachos y Seminarios). All the remaining presentations will take place in the Classroom Building (Aulario). A detailed enumeration of the main campus locations is provided below, with corresponding reference on the accompanying figure.

(1) Pedestrian entrance
(2) Office and Seminar Building (Edificio de Despachos y Seminarios)
(3) Classroom Building (Aulario)
(4) INDESS (Instituto Universitario para el Desarrollo Social Sostenible)
(5) Cafeteria Dining Area
(6) Cafeteria Terrace
(7) Parking
(8) Entrance for pedestrians and vehicles
(9) Entrance for pedestrians and vehicles



Campus de Jerez main locations at the Universidad de Cádiz (UCA).

Please find below the assigned rooms in each building for the scheduled sessions.

- (2) Office and Seminar Building (Edificio de Despachos y Seminarios):
  - Entrance Hall (Registration).
  - Auditorium - Salón de Actos (Opening Session and EWGLA session).
- (3) Classroom Building (Aulario):
  - Room 1.20A, 1st Floor (Parallel Sessions).
  - Room 1.20B, 1st Floor (Plenary and Parallel Sessions).
- (4) INDESS:
  - Entrance stairs (Group Photo).
  - Auditorium - Salón de Actos (Spanish Network Location Session).

Additional Points of Interest Near the University

For the convenience of our conference attendees, here are several useful locations within walking distance of the university campus:

- Restaurants and Cafés. There are several restaurants and cafés located directly across the street on Avenida de la Universidad.
- Bus stops. Multiple bus stops are located near on Av. de la Universidad: (1) (2).
- Taxi Stand Parada de taxis (La Vid).
- ATM and Bank Branches (Paseo de las Delicias).
- Supermarket (Av. Alcalde Jesús Mantaras).
- Pharmacy (c/ Camino de Albadalejo, 2).
- Police station (Av. de la Universidad).

Interactive map

This interactive map provides detailed information on all conference venues as well as notable points of interest in the city of Jerez. The map can also be accessed by scanning the QR code below.

QR access to interactive map with conference venues and points of interest.

Wi-Fi

Internet access at the university will be provided through the **eduroam** network. More information here: eduroam.uca.es.
The **ucAir** network is especially recommended for guests who require occasional access to the network. To connect to ucAir, select the network on your device and when prompted for a password, enter: `caminantenohaycamino`. Please note: If you do not open your browser and enter your login credentials, you will not have access to the Internet.

Social Activities

Welcome reception on Wednesday, September 17, 2025

The welcome reception will take place at 8 pm at Damajuana located at c/ Francos, 18.

Activities on Thursday, September 18, 2025

On Thursday, we will have a two activities. The activities will start at 6 pm and it takes approximately 10 minutes on foot to move from one activity to the other. Due to limited capacity for the visits, participants will be divided into two groups, with each group participating in the activities in alternating order.

- Flamenco at Peña Flamenca Buena Gente (Plaza Basurto). Two main activities are planned: a talk-workshop and a brief live performance. These experiences will introduce attendants to a key part of Andalusian culture.
- Winery at González Byass (Bodega Tío Pepe) (c/ Manuel María González). We will learn about the region's unique sherry production process, from vineyard to barrel. The experience concludes with a guided tasting of several sherry varieties.

Conference dinner on Friday, September 19, 2025

On Friday, our Conference Dinner will begin at 8:30 pm at Jardín de la Catedral, the González Byass restaurant located at Plaza de la Encarnación.

Partner Institutions and Sponsors

The organizers are very grateful to the following partner institutions and sponsors.

The 30th EWGLA 2025 has been partially supported by Grant RED2022-134149-T funded by MICIU/AEI/10.13039/501100011033 and PLAN PROPIO-UCA 2025-2027.

PLAN PROPIO UCA 2025-2027