WARP 5

5th International Workshop on Arc Routing Problems, Vienna (Austria), May 22-23, 2025

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5th International Workshop on Arc Routing Problems
22-23 MAY 2025
VIENNA, AUSTRIA

Workshop Venue

University of Vienna

The University of Vienna was founded in 1365. With more than 180 degree programs and about 92,000 students, the University of Vienna is the largest and most diverse educational institution in Austria. The University of Vienna is a research university enjoying high international visibility. Its profile reflects the characteristics of the area it is located in, and understands research as a global challenge.

The workshop takes place at "alte Kapelle"("old chapel") on the first floor at the University Campus "altes AKH" in Vienna. Google maps link

Please note that access to the first floor is ony possible via stairs, there is no elevator available. Please let us know if you need assistance!

You can find a map of the Campus here, with "alte Kapelle" being right in the center, between "Hof 1" and "Hof 2" (courtyard 1 and 2) . On this map you also see public transport: tramway lines 5, 43, 44 serve "Spitalgasse" right next to the Campus.

Also, tramway stop "Schwarzspanierstraße" is an 8 minute walk away, it is served by lines 37, 38, 40, 41, 42.

The closest underground stop is "Schottentor", served by purple line U2. It is a 15 minutes walk to the venue, or take tramway 43 or 44.

General Information

Registration & Information Desk The Registration & Information Desk is situated in „alte Kapelle"

Internet Access WiFi is available through your eduroam account. If you do not have an eduram account, please go to the Information Desk to get WiFi access.

Badges are required to access the lunch area. However, we encourage all attendees to wear the badges at all sessions and events.

Coffee breaks Coffee will be served in the „alte Kapelle" during the coffee breaks indicated in the Conference Program.

Lunch will be provided at Bierheuriger Gangl 12.30 to 13. 30. Please bring your conference badge to lunch! Bierheuriger Gangl is located 250 metres walking distance from the conference

Guidelines for Speakers

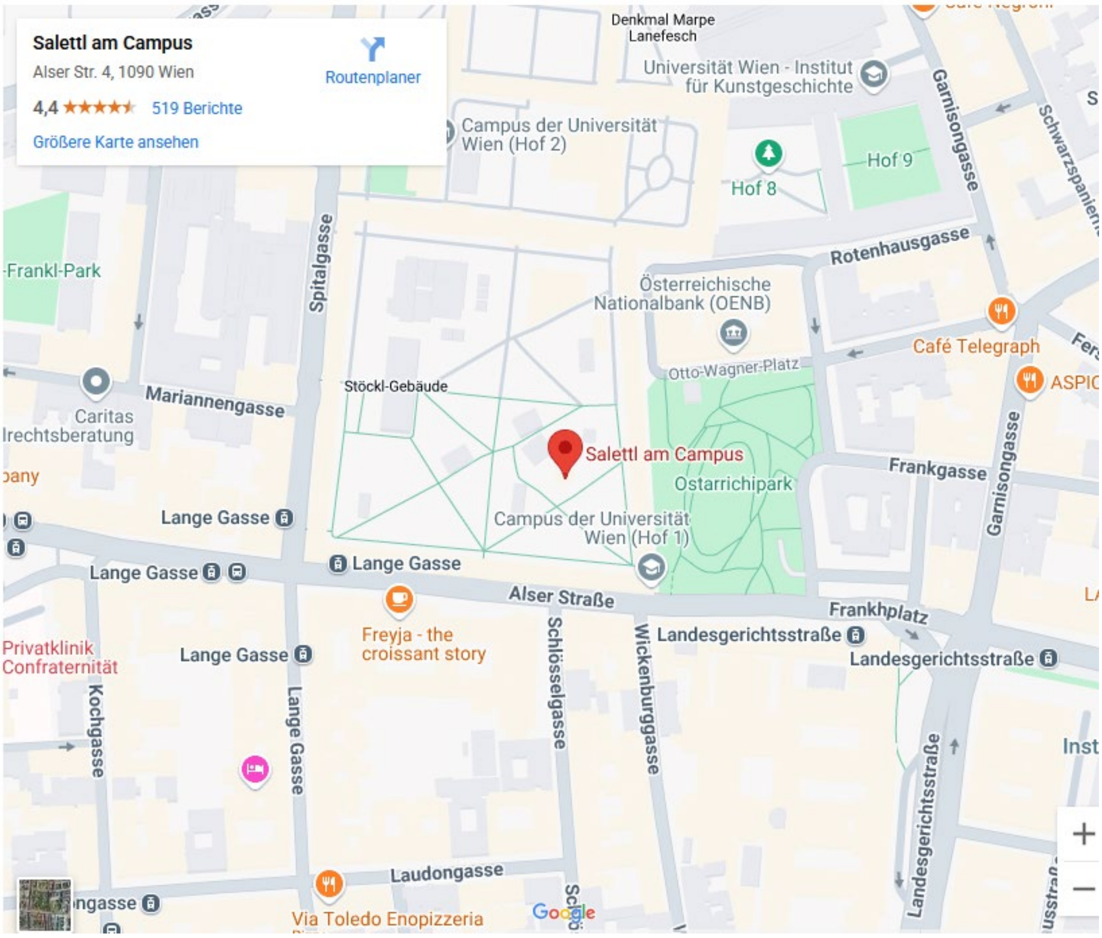
All sessions will be held in the „alte Kapelle" The room is equipped with a computer and a projector.

Please bring your presentation as **pdf-file** or **pptx-file** on a USB memory-stick and copy it on the computer before the session starts.

Please limit your presentation to the designated time span of **25 minutes**, to allow for 5 minutes of discussion after each presentation. The session chair is responsible for time keeping.

Social Events

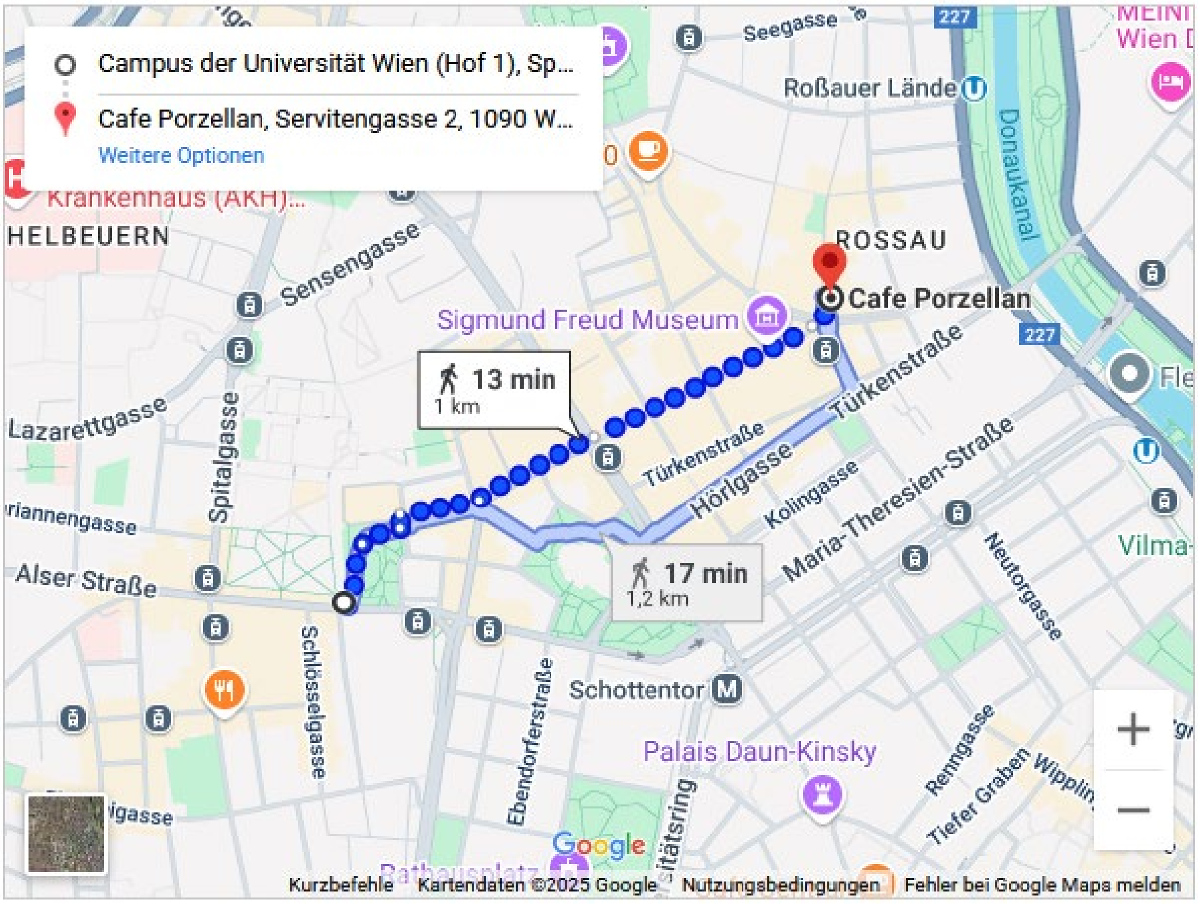
Welcome Party 21.05 5:30 pm , Salettl am Campus, Alsterstraße 4,1090 Vienna



Conference Dinner

The easiest way to get to the conference Dinner is to walk 10-15 minutes or by the underground lines **U2** or **U4**, exit "**Schottenring**", or by taking **tram D** until exit "**Schlickgasse**".

22.05 06:30 pm Restaurant Porzellan, Servitengasse 2, 1090 Vienna



WARP 5

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Thursday 22.05.2025

08:45-10:30 Opening and session 1. Chairs: Karl Doerner and Sanne Wøhlk	
Sanne Wøhlk	Why arc routing is interesting
Alexander Ingemann Lindhardt	Solving the CARP using Logic-Based Benders Decomposition
Rafael Martinelli	The Capacitated Arc Routing Problem with Zigzag Options
10.30-11.00 coffee break	
11.00-12.30 Session 2. Chair: José Belenguer	
Teresa Corberán	The Periodic drone Arc Routing Problem with Irregular Services
Islam Altin	Drone-Based Surveillance System for Campus Security
Raquel Bernardino	Inspecting Electric Lines with Drones
12.30-14.00 Lunch	
14.00-15.30 Session 3. Chair: Elena Fernández	
Demetrio Laganá	The Periodic Capacitated Arc Routing Problem with Irregular Services
Juan Sebastian Riveros Perez	Solving the Mixed Capacitated Arc Routing Problem with Intermediate Facilities and Stochastic Demands
Marcos Negreiros	The Twin Rural Postman Problem: Basics, Methods and Application Results
15.30-16.00 coffee break	
16.00-17.00 Session 4: Chair: Karl Doerner	
Maier Thomas	Invited practitioner, Fagus Consulting
Pavel Cimili	Sensor allocation and snow approximation strategies in time-dependent dynamic snowplowing problems

18:30 Dinner Restaurant Porzellan , Servitengasse 2,1090 Vienna

Why is Arc Routing Interesting?

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In this presentation, we will take a look at the structural differences between node routing and arc routing, and we will explore what those differences mean for the way we approach the problems. This tour around arc routing structure will take us through splitting and a look at the triangle inequality.

When discussing lower bounds, we will revisit the work of the renowned mathematician Euler (1707–1783) and we will take a look at some interesting neighborhood structures that can be used in meta-heuristics for arc routing.

Solving the CARP using Logic-Based Benders Decomposition

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Solving the CARP to optimality can be beneficial for many road-based logistical problems such as postal delivery or garbage collection. Currently, the state-of-the-art exact algorithm for the CARP is the branch-cut-and-price capable of solving instances with upwards of 190 required edges [1].

In this presentation, the use of Logic-Based Benders Decomposition [3] will be explored as an alternative approach to optimally solve large CARP instances. Specifically, the following decomposition will be discussed: The master problem is in charge of assigning required edges to each vehicle and the subproblem creates optimal routes given the assigned edges. This subproblem is particularly interesting, as it can be decoupled into independent problems for each vehicle. The general case of each subproblem is the RPP with the CPP being a special case. When the required edges in a given subproblem form a single connected component, the subproblem can be solved efficiently using matchings. Alternatively, the RPP can be solved fully by the branch-and-cut algorithm of [2]. In the presentation, we present preliminary results and discuss various implementational choices.

References

[1] D. Pecin, E. Uchoa, "Comparative Analysis of Capacitated Arc Routing Formulations for Designing a New Branch-Cut-and-Price Algorithm", *Transportation Science* 53(6), 1673-1694, 2019.

[2] G. Ghiani, G. Laporte, "A branch-and-cut algorithm for the Undirected Rural Postman Problem", *Math. Program.* 87, 467-481, 2000.

[3] J. Hooker, *Logic-Based Benders Decomposition - Theory and Applications*, Springer, 2024.

The Capacitated Arc Routing Problem with Zigzag Options

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Thibaut Vidal
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The Capacitated Arc Routing Problem with Zigzag Options (CARP-Z) arises in applications such as postal delivery, waste collection, and snow plowing, where certain streets require service on both sides. Let $G = (V, E)$ be a connected graph with node set V and edge set E. A subset of edges, $E_S \subset E$, must be serviced exactly once (single edges) and represents streets requiring a standard traversal. Another subset, $E_D \subset E$, must be serviced twice (double edges), either by two separate traversals (not necessarily in opposite directions) or by a single *zigzag* traversal.

The objective of CARP-Z is to determine a set of minimum-cost vehicle routes, where each route starts and ends at the depot, each single edge is serviced exactly once, and each double edge is serviced either twice by normal traversals or once using a zigzag pass. Additionally, the total demand of serviced edges assigned to any vehicle must not exceed its capacity.

CARP-Z is NP-hard as it generalizes the classical CARP. Despite its practical importance, it has received little attention in the literature. This work introduces a hybrid metaheuristic and an exact branch-cut-and-price (BCP) algorithm for solving CARP-Z. Our metaheuristic extends the Unified Hybrid Genetic Search (UHGS) framework initially proposed by [1] for CARP and related problems with *mode choices*. It incorporates two additional modes to represent zigzag services and uses a tailored dynamic programming approach to evaluate associated costs efficiently. The BCP algorithm generates non-elementary routes using a specialized pricing procedure and improves solutions by separating specific families of cuts adapted from the literature. Computational experiments on benchmark instances demonstrate both methods' strong performance and highlight promising future research directions.

References

[1] T. Vidal, “Node, edge, arc routing and turn penalties: Multiple problems — one neighborhood extension”, *Operations Research* 65.4: 992-1010, 2017.

The Periodic drone Arc Routing Problem with Irregular Services

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In this work, we address the Periodic drone Arc Routing Problem with Irregular Services (PdARP). We consider a finite and discrete time horizon and a set of periods, and a set of edges that must be traversed (required edges) by a single drone. Each required edge has a frequency associated with each period that indicates the minimum number of times that the edge must be serviced along the days of the period (we assume that a required edge must be serviced at least once over the time horizon). However, a required edge can be traversed in each period a number of times greater than the given frequency if the maximum distance the drone can travel allows it (but not more than once a day). We consider that these additional traversals of the required edges are beneficial, so each required edge has a benefit associated.

The problem consists of finding a set of routes, one for each day, satisfying the service requirements of each edge while not exceeding the maximum distance the drone can travel. The goal is to maximize the benefit obtained from the additional traversal of the required edges.

In this talk, we present a formulation for the problem and a branch-and-cut algorithm and a Kernel Search to solve it, as well as some computational results on a set of instances with different characteristics.

Drone-Based Surveillance System for Campus Security

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Drone-assisted operations are used in various fields such as logistics, agriculture, disaster management and security. In this study, monitoring operations are conducted with drones to ensure campus security. Because, drones provide real-time surveillance by quickly monitoring large areas. The areas requiring surveillance within the campus environment have been defined as edges. Therefore, drones must perform edge monitoring operations with their limited energy capacity. Besides, drones are located in multiple depots, but it is not mandatory to use all of the depots. Considering all these conditions encountered in drone-assisted campus security operations, the optimal drone route should be determined. This problem is addressed as the Multi-Depot Drone Arc Routing Problem (MD-DARP) in this study. The objective of this problem is to obtain the optimal drone route that minimizes the total distance traveled. Moreover, this study also considers the structure where the edges are clustered based on drone types. In this case, not every drone can monitor every edge, so there are compatibility constraints for the drones. This problem is tackled as the Site-Dependent Drone Arc Routing Problem (SD-DARP). A mixed integer mathematical model was developed and a metaheuristic algorithm was used to solve MD-DARP and SD-DARP. Real-world test problems were generated to evaluate the performance of the solution methods. Finally, computational results are discussed, in detail.

Acknowledgement: This study was supported by the Scientific and Technological Research Council of Turkey (TUBITAK)-2219 International Postdoctoral Research Fellowship Program.

Inspecting Electric Lines with Drones

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

Acknowledgments: this work was partially supported by the Projects CEMAPRE/REM - UIDB /05069/2020, financed by FCT/MCTES through national funds.

References

[1] Á. Corberán, R. Eglese, G. Hasle, I. Plana, and J.M. Sanchis, “Arc routing problems: A review of the past, present, and future”, *Networks*, 77 (1), 88-115, 2021.

[2] A. Corberán and G. Laporte (Eds), '*Arc Routing: Problems, Methods, and Applications*', MOS-SIAM Series on Optimization, 2014.

[3] M.C. Mourão, and L.S. Pinto, “An updated annotated bibliography on arc routing problems ”, *Networks*, 70 (3), 844-194, 2017.

The Periodic Capacitated Arc Routing Problem with Irregular Services

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The study of operational issues in the field of distribution logistics includes the formulation of combinatorial optimization problems, wherein the objective is the minimization of costs incurred due to the service provided by vehicles. In numerous applications, the service is performed when traversing specific links connecting two locations and the result is the definition and solution of an Arc Routing Problem (ARP). Real applications of ARPs occur in several contexts ([1]). This work addresses the Periodic Capacitated Arc Routing Problem with Irregular Services ($PCARP$–IS) on mixed graphs. For each period within a planning horizon, the $PCARP$–IS aims to schedule a fleet of capacitated vehicles to meet the demands of all required links, accounting for irregular services and minimizing the total routing costs. A real application of this problem is in the context of on-demand garbage collection, where the waste collection frequency can vary according to the volume of waste produced during the week along the streets. These activities are typically conducted on a periodic basis, and different roads may have different service requirements (number of visits, etc.) depending on their importance within the network. This work provides a methodological contribution by devising a new matheuristic approach, which is built upon a novel route-based Integer Linear Program (ILP) formulation of the $PCARP$–IS and the framework of the multi-start local search algorithm. The results demonstrate the effectiveness of the matheuristic algorithm compared to an exact method and a hybrid heuristic from the literature for the Periodic mixed Rural Postman Problem with Irregular Services ([2, 3]). Additional computational tests demonstrate the impact of the vehicle capacity in solving the problem effectively, in comparison with the case in which no capacity constraints are considered.

References

[1] Á. Corberán, R. Eglese, G. Hasle, I. Plana and J.M. Sanchis, "Arc routing problems: A review of the past, present, and future", *Networks* 77(1), 88-115, 2021.

[2] E. Benavent, Á. Corberán, D. Laganà and F.Vocaturo, "A two-phase hybrid algorithm for the periodic rural postman problem with irregular services on mixed graphs", *European Journal of Operational Research* 307(1), 64-81, 2023.

[3] E. Benavent, Á. Corberán, D. Laganà and F.Vocaturo, "The periodic rural postman problem with irregular services on mixed graphs", *European Journal of Operational Research* 276(3), 826-839, 2019.

Solving the Mixed Capacitated Arc Routing Problem with Intermediate Facilities and Stochastic Demands

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The Mixed Capacitated Arc Routing Problem with Intermediate Facilities and Stochastic Demands (MCARP-IF-SD) extends classical capacitated arc routing problems by integrating stochastic demands and intermediate facilities in mixed graphs, allowing vehicles to reset capacities along the route. This study aims to both construct real-world problem instances and develop a solution approach to optimize waste collection operations in Greater Montreal, specifically Longueuil, QC.

Developing these instances presents several methodological challenges. One key issue is identifying required and non-required links (arcs and edges). The available event-based GPS data, recorded at irregular intervals (10–30 seconds apart), captures vehicle speed and position but does not explicitly indicate which links were serviced. We analyzed speed variations and event frequency per link to infer service activity.

Another challenge is demand assignment, as waste accumulation is recorded only when vehicles reach a dump site, where the total collected demand is aggregated. Since this data lacks direct correspondence to serviced links, demand distribution across road segments must be estimated using dump records and reconstructed routes. This reconstruction relies on a map-matching algorithm, which assigns GPS traces to the network but introduces challenges in distinguishing between valid assignments and errors. Dead-end streets and parallel edges with identical endpoints complicate this process, making it difficult to determine whether consecutive antiparallel arcs are accurately assigned or misclassified.

To validate these instances, the deterministic version of the problem, excluding intermediate facilities, was solved using the Unified Hybrid Genetic Search (UHGS) algorithm developed by Vidal [1]. Results indicate an average 18.79% reduction in distance traveled across 10 instances compared to current operational strategies, highlighting the potential of optimization-based approaches for enhancing waste collection efficiency.

References

[1] T. Vidal, "Node, Edge, Arc Routing and Turn Penalties: Multiple Problems—One Neighborhood Extension", *Operations Research* 65(4), 992–1010, 2017.

The Twin Rural Postman Problem: Basics, Methods and Application Results

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This work considers a new arc routing problem born in domiciliary waste collection, particularly in metropolitan suburban areas and in a full on major Brazilian municipalities. In the problem a sector must be covered in a number of trips between all required street segments and special collection points, but each trip can be divided between the vehicle and one collector. The required streets visited by the collector may not be passed by the vehicle, who on foot collects the garbage and leave it in the closest corner where the vehicle will pass later. The problem wishes to minimize the cost of both traversals, where the route performed by the collector can start and end from any corner, while the vehicle departs and ends its route accordingly the trip it is performed (Garage-circuit-Dump site, Dump-circuit-Dump or Dump-Garage-Dump). The Twin Rural Postman Problem is a notorious multi-objective NP-Hard problem in any of its versions (Symmetric, Oriented, Mixed, Generalized or Windy) because it is related to a set-partitioning problem, and the open rural postman problem. We propose a multi-objective column generation approach to solve the problem, a guided semi-automatic approach and a GRASP meta-heuristic for the problem. Finally we evaluate an application of the proposed methodology for two downtown sectors of the city of Andradina/SP where we measured an expressive reduction of 45% in walking distance by the collectors (reduction of 3-4.5h in daily work), while also minor reducing the distance on the vehicle's travel. Applying this methodology we propose weekly vehicle routes reduction that reaches 23% in vehicles' tours for 8 sectors.

This is a project of CT&I Transport supported by CNPq with grant 407652/2022-1.

Sensor allocation and snow approximation strategies in time-dependent dynamic snowplowing problems

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Climate change is intensifying winter storms and making them increasingly unpredictable, creating a pressing need for agile, data-driven solutions in snow removal and winter maintenance. Accurate, localized measurements of snow accumulation are crucial for efficient route planning, ensuring public safety, and managing operational resources. To demonstrate the importance of real-time data in dynamic route planning, we propose a rolling horizon framework that integrates simulated sensor-based snow-level monitoring with several methods for snow-level approximation. As our focus is on serving streets with multiple vehicles, we formulate the resulting routing task as a team orienteering arc routing problem (TOARP), where maximizing overall safety is represented by a profit-based objective.

We compare multiple sensor placement strategies—including grid-based, priority-based, and clustering—alongside different snow-cover estimation techniques, such as kriging or proximal interpolation, to evaluate their performance and identify the best combinations under varying storm conditions. This snow-cover information is processed within an Adaptive Large Neighborhood Search (ALNS) metaheuristic that plans routes for a 20-minute horizon, followed by a one-minute re-optimization focusing on the subsequent 10 minutes. Such a rolling horizon scheme with a "look-ahead" procedure strikes a balance between computational feasibility and frequent updates. We test our framework on a real-world street network from Vienna, Austria, highlighting how the choice of sensor placement and estimation methods can significantly influence route efficiency, resource allocation, and public safety in volatile storm scenarios.

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Friday 23.05.2025

09.00-10.30 Session 5. Chair: Demetrio Laganà	
Karl Dörner	A rolling horizon framework for the time-dependent multi-visit dynamic safe street snow plowing problem
Elena Fernández	The Multiple-Picker Order Assigment Routing Problem
Darius Arbabha	A Combinatorial Approach to solving the Capacitated Arc Routing Problem
	10.30-11.00 coffee break
11.00-12.30 Session 6. Chair: Rafael Martinelli	
Jahir Llagas	Mechanics-Based Energy-and-Fuel Consumption Models in Arc Routing Problems
Vahid Akbari	Exact and heuristic methods for deploying electrified road systems on transportation networks
Isaac Plana	Solving the Min Max Multi-trip Loaction Arc Routing Problem with a branch-and-price algorithm
	12.30-14.00 Lunch
14.00-15.30 Session 7. Chair: Candida Mourão	
Wenjin Yan	The Undirected Team Orienteering Arc Routing Problem: Formulations, Valid Inequalities, and Exact Algorithms
Simona Mancini	Multimodal Tourist Trip Design with nodes and arcs profit
	15:00-15.30 coffee break
Chahid Ahabchane	Optimization of snow removal operations on sidewalks
15.30 Closing of Workshop	
	15.40-16.00 coffe break

A rolling horizon framework for the time-dependent multi-visit dynamic safe street snow plowing problem

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As a major real-world problem, snow plowing has been studied extensively. However, most studies focus on deterministic settings with little urgency yet enough time to plan. In contrast, we assume a severe snowstorm with little known data and little time to plan. We introduce a novel time-dependent multi-visit dynamic safe street snow plowing problem. A time-discretized mixed integer program would be very challenging to solve, even if snowstorm movement is predictable; therefore, we address the problem on a rolling time horizon. The proposed framework splits the problem into smaller problems, and predicts the future snowfall and the state of the system before solving each subproblem. The subproblems are, hence, considered to be deterministic and solutions are generated using aaptive large neighborhood search. Due to considering a real-world problem with dynamic changing data, the rolling horizon framework has only a very limited computation time to calculate a solution for a given subproblem, therefore a metaheuristic solution technique is used. During this time, the solution for the previous subproblem is executed. We validate the efficacy of the adaptive large neighborhorhood search on team orienteering arc routing problem benchmark instances.

We create real-world-based instances for the city of Vienna and examine the effect of (i) different snowstorm movements, (ii) having perfect information, and (iii) different information-updating intervals and look-aheads for the rolling horizon method. Our findings show that different snowstorm movements have no significant effect on the choice of rolling horizon settings. They also indicate that (i) larger updating intervals are beneficial, if prediction errors are low, and (ii) larger look-aheads are better suited for larger updating intervals and vice versa. However, we observe that less look-ahead is needed when prediction errors are low.

The Multiple-Picker Order Assigment Routing Problem

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We address the Multiple-Picker Order Assignment Routing Problem (M-POARP). The M-POARP belongs to the class of Order Routing Problems, which 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 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 consists of one or more items, located at different places in the warehouse. The orders are grouped 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 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 that models the M-POARP as a min-max variant of 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.

A Combinatorial Approach to solving the Capacitated Arc Routing Problem

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The ComRoute project is devoted to solving the capacitated arc routing problem (CARP) and related problems to optimality with a method that operates purely in an integral space. It is an uncommon approach based on the initial idea of [1] to solving NP Problems and combines the following four core ideas: Combinatorial lower bounds, Double-Bounding, Combinatorial branching, and Avoidance of re-calculation.

The approach operates within a Branch & Bound framework. The whole process is done without the use of linear programming and is purely based on the special structures of the problems and the use of combinatorial lower bounds that take advantage of these structures. Combinatorial lower bounds are derived utilizing the special structure of the problems and are used to determine a lower bound value in each branch node of the search tree, instead of using the traditional LP-relaxation lower bound. For the CARP, we use the NDLB [2]. For other optimization problems, their special structures will lead to other combinatorial lower bounds. Combinatorial branching refers to working in an integral solution space only in which branching is performed by utilizing the information obtained from the Double-Bounding. Decisions that seem to prevent better bounds are candidates for branching. The procedure thereby avoids fractional values completely. Avoidance of re-calculation is possible here because of the matching problem solved inside the lower bounds in the Branch & Bound tree, this lower bound only needs to be partially recalculated in each branch, because intermediate solutions of the matching can be reused. The avoidance of a fractional solution space, but usage of efficient alternatives utilizing the special structure of problems should allow for competitive solution times and handling of bigger instances.

References

[1] R. Hirabayashi, N. Nishida, and Y. Saruwatari. Tour Construction Algorithm for the Capacitated Arc Routing Problem. Asia-Pacific Journal of Operational Research, 9:155–175, 1992.

[2] R. Hirabayashi, N. Nishida, and Y. Saruwatari. Node Duplication Lower Bounds for the Capacitated Arc Routing Problem. Journal of Operations Research, Society of Japan, Vol. 35, No. 2, June 1992.

Mechanics-Based Energy-and-Fuel Consumption Models in Arc Routing Problems

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Transportation plays a crucial role in logistics and goods distribution, and its efficiency largely depends on the energy or fuel consumption of the vehicles used. However, accurately modeling this consumption is challenging, as it is influenced by multiple mechanical factors such as speed, vehicle mass, aerodynamic resistance, and drag forces. Despite its importance, many traditional routing models oversimplify these relationships by assuming constant speeds, fixed travel times, and a linear relationship between consumption and distance traveled. In classical vehicle routing models for conventional fuel-powered vehicles, there is generally no explicit restriction on vehicle range, assuming that fuel supply is unlimited within the planning horizon and that only capacity and time constraints apply. In contrast, more recent models developed for electric vehicles explicitly consider range and recharging limitations, but often with simplifications that do not accurately represent real-world energy consumption. These oversimplifications can lead to infeasible or suboptimal solutions when applied in real-world scenarios.

This work generalizes energy and fuel consumption functions based on mechanics models into time-dependent routing problems. As a case study, we introduce the Electric Time-Dependent Capacitated Arc Routing Problem (E-TDCARP), extending the traditional arc routing problem with time-dependent travel and battery capacity constraints. A preprocessing method transforms nonlinear consumption functions into computationally manageable representations, and a metaheuristic approach is applied to solve the problem using benchmark instances.

The comparison between TDCARP and E-TDCARP demonstrates the impact of explicitly modeling energy consumption in routing. This study contributes to more robust and computationally efficient methodologies, improving the reliability and applicability of routing models in real-world scenarios.

Exact and heuristic methods for deploying electrified road systems on transportation networks

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The Electric Road System (ERS) is an advanced technology that enables electric vehicles (EVs) to recharge while in motion, extending their range and optimizing battery use. This innovation is particularly beneficial for logistics companies aiming to expand EV adoption efficiently, especially for long-haul transport. This study focuses on optimizing ERS deployment to maximize electrification coverage by strategically placing electrified road segments and designing routes that eliminate the need for recharging stops. We first formulate a mathematical model of the problem and use it to solve small-scale instances optimally. To address larger cases, we develop Lagrangean relaxation (LR), branch-and-price, and matheuristic methods. To evaluate their performance, we conduct an extensive computational study using Sioux Falls data and present sensitivity analyses on key parameters. Our results show that all three methods achieve optimal solutions across various scenarios, with the LR method providing tight lower bounds. Additionally, we present a case study using a comprehensive dataset of freight transport volumes on the U.S. highways to further assess algorithmic performance and provide managerial insights. The proposed methods exhibit similar performance, consistently finding optimal solutions where known. Moreover, our findings suggest that strategically electrifying up to 12% of the U.S. road network could enable more than 52% of trucks to transition to EVs, allowing them to complete daily trips without requiring recharging stops.

Solving the Min Max Multi-trip Loaction Arc Routing Problem with a branch-and-price algorithm

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This work addresses the Min Max Multi-Trip Location Arc Routing Problem (MM-MT-LARP), which combines arc routing and location problems. In the MM-MT-LARP, we have an undirected graph containing a subset of required edges that must be traversed to perform services such as surveillance or inspection. A subset of vertices acts as potential depots, each with an associated opening cost. We have a fixed number of vehicles with limited autonomy. Each vehicle departs from one of the selected depots and can travel a maximum distance before returning to the depot. Once there, its battery can be replaced to continue performing another route. We assume that the number of routes each vehicle can perform is unlimited and the time required for battery replacement is negligible. The goal is to select the set of depots to open and design the routes for each vehicle so that the maximum cost among all vehicles (summing the cost of the vehicle routes and the depot opening cost) is minimized. This problem has applications in the use of drones, where each potential depot is a possible launching point for a drone, which is carried by a ground vehicle from a central depot to its launching point. In this case, the opening cost corresponds to the travel time of the ground vehicle from the central depot to the launching point and back, and we aim to minimize the maximum travel time, i.e., finish the job as soon as possible. We present a branch-and-price algorithm for solving the MM-MT-LARP, tested on a set of instances of the Min Max Multi-Trip Drone Arc Routing Problem. This similar problem involves drones as the service vehicles, implying that the graph induced by the non-required edges is complete (since drones do not need to follow the network links). The results are compared with those obtained by an existing branch-and-cut algorithm, showing that the proposed method is more efficient in both execution speed and the number of instances optimally solved. Additionally, we have generated a new set of instances for the MM-MT-LARP with non-complete graphs to test the performance of the presented algorithm in such cases.

The Undirected Team Orienteering Arc Routing Problem: Formulations, Valid Inequalities, and Exact Algorithms

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We address the Undirected Team Orienteering Arc Routing Problem. In this problem, demand is placed at some edges of a given undirected graph and served demand edges produce a profit. Feasible routes must start and end at a given depot and there is a time limit constraint on the maximum duration of each route. The problem asks for a set of $|K|$ maximum profit routes. We exploit optimality conditions for this problem and propose two new undirected formulations with binary variables. We also introduce a Logic-Based Benders decomposition based on these formulations and show how to strengthen the Logic-Based Benders cuts. Furthermore, we design several new families of valid inequalities, including inaccessible traversal inequalities, clique and independent set inequalities (derived from conflict graphs), symmetry breaking constraints, and strengthened Logic-Based Benders cuts, and problem-specific heuristics to improve the performance of exact algorithms. Extensive computational tests are conducted to examine the performance of the proposed formulations, valid inequalities, and heuristics. Our findings highlight the pivotal role of Logic-Based Benders decomposition and conflict graphs in solving the UTOARP, marking their first application in the context of arc routing problems to the best of our knowledge. Moreover, these techniques hold promise for advancing solution approaches in broader arc routing contexts.

Multimodal Tourist Trip Design with nodes and arcs profit

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The problem of designing personalized touristic itineraries has been broadly addressed in the literature. In its simplest version, it can be modeled as a Team Orienteering Problem (TOP). However, for a more realistic representation of the problem, several additional features must be taken into consideration. This work introduces the Multimodal Tourist Trip Design Problem with profit on nodes and arcs (MTTPD-NAP), in which several transportation modes can be used to move across the city, each associated with a different cost and trave time, and the profit can be associated to both nodes and arcs. This typically represents cases in which some arcs assume a relevant touristic interest, such as the Champs Elysee in Paris, or the 5th Avenue in New York. Conversely, some arcs, located in district with a high criminal risk or a high level of pollution, may be associated with a negative profit, if covered by walking. Furthermore nodes may require the payment of a ticket to be visited and are associated with a minimum visit time, necessary to complete the related activity and earn the profit. The goal is to design m disjointed trips, one for each day spent in the city, in order to maximize the profit collected while respecting budget constraint and a maximum walking time per day. We provide a Mixed Integer Programming model and a large neighborhood search matheuristic to effectively handle the problem. Results are conducted on real instances including up to 50 attractions located in New York City.

References

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Optimization of snow removal operations on sidewalks

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Winter maintenance is essential for safe urban mobility, but represents a significant budgetary expense, especially in snow-prone regions. This research addresses the optimization of sidewalk snow removal, a task often overlooked compared to road plowing. We conduct a comparative analysis with traditional road snow removal. We propose an Arc Routing Problem model with multiple passes and priorities constraints. To address the computational complexity of this optimization problem, we implement metaheuristic algorithms. These algorithms are applied to a real-world case study, utilizing data from the City of Rouyn-Noranda, with the primary objectives of minimizing operational costs and significantly enhancing service quality. By providing a data-driven approach to sidewalk snow removal, this research aims to offer municipalities a practical and efficient tool for improving winter mobility.