Hội thảo

TỐI ƯU TRONG KỶ NGUYÊN CÔNG NGHIỆP 4.0

(Optimization in the Era of Industry 4.0)

02–03/05/2020
Hà Nội, Việt Nam

Chương trình hội thảo

Tóm tắt báo cáo

Danh sách đại biểu

Viện Toán học

Viện Hàn lâm Khoa học và Công nghệ Việt Nam

Đơn vị tài trợ

- Viện Toán học - Viện Hàn lâm Khoa học và Công nghệ Việt Nam (đề tài ĐLTE00.02/19-20)

Cơ quan tổ chức

- Viện Toán học - Viện Hàn lâm Khoa học và Công nghệ Việt Nam
- Đại học Phenikaa

Ban tổ chức

- Hà Minh **Hoàng** (Đại học Phenikaa, *đồng trưởng ban*)
- Phong Thị Thu **Huyền** (Viện Toán học, *thư ký*)
- Lê Xuân **Thanh** (Viện Toán học, *đồng trưởng ban*)
- Nguyễn Trung **Thành** (Đại học Phenikaa)

Liên hệ

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CHƯƠNG TRÌNH HỘI THẢO

Thứ bẩy, ngày 2 tháng 5 năm 2020

Buổi sáng

- Trực tiếp tại Hội trường 703 tầng 7 nhà A6 Đại học Phenikaa, phường Yên Nghĩa, quận Hà Đông, thành phố Hà Nội.
- Trực tuyến trên https://zoom.us/join, Meeting ID: 817-9409-7726, Password: 743228.

Chủ tọa: **Lê Xuân Thanh**

09:00 – 09:15	Khai mạc và giới thiệu đại biểu
09:15 – 10:00	**Mai Anh Tiến** (Học viện Công nghệ Massachusetts) *Robust multi-product pricing* *under general discrete choice models*
10:00 – 10:30	**Dương Thị Kim Huyền** (Viện Toán học) *Affine minimax variational inequalities* *and two-person matrix games*
10:30 – 11:00	**Đỗ Thị Minh Thúy** (Université de Montréal, Canada) *Vehicle routing with transhipment facilities, time windows* *and time-dependent travel times on a road network*
11:00 – 11:10	**Giải lao**
11:10 – 11:40	**Vũ Thị Hướng** (Viện Toán học) *Visual descriptions for* *solutions of some parametric optimal control problems*
11:40 – 12:10	**Nguyễn Minh Hải** (Đại học Công nghệ - ĐHQGHN) *Improved results for the minimum distance superset problem*

Thứ bẩy, ngày 2 tháng 5 năm 2020

Buổi tối

- Trực tuyến trên https://zoom.us/join, Meeting ID: 817-9409-7726, Password: 743228.

Chủ tọa: **Hà Minh Hoàng**

20:00 – 20:45 **Nguyễn Trung Thành** (ORLab, Đại học Phenikaa)
Fair and efficient resource allocation:
computational complexity and algorithms

20:45 – 21:15 **Hà Minh Hoàng** (ORLab, Đại học Phenikaa)
The vehicle routing problem with synchronization constraints

21:15 – 21:45 **Nguyễn Minh Anh** (ORLab, Đại học Phenikaa)
The min-cost parallel drone scheduling vehicle routing problem

21:45 – 21:55 **Giải lao**

21:55 – 22:25 **Đàm Tiến Thành** (ORLab, Đại học Phenikaa)
Joint chance-constrained staffing optimization
in multi-skill call centers

22:25 – 22:55 **Vũ Duy Mạnh** (Ecole Polytechnique de Montréal, Canada)
Online stochastic optimization
of radiotherapy patient scheduling

Chủ nhật, ngày 3 tháng 5 năm 2020

Buổi sáng

- Trực tuyến trên https://zoom.us/join, Meeting ID: 896-8339-8794, Password: 559118.

Chủ tọa: **Nguyễn Trung Thành**

09:00 – 09:45 **Dương Thị Việt An** (Viện Toán học)
The most fundamental parts of convex analysis and its applications to optimization

09:45 – 10:15 **Đỗ Đức Đông** (Đại học Công nghệ, ĐHQGHN)
Ants can solve the parallel drone scheduling traveling salesman problem

10:15 – 10:45 **Lê Xuân Thanh** (Viện Toán học)
A binary linear programming approach for timetabling in Vietnamese schools

10:45 – 10:55 **Giải lao**

10:55 – 11:25 **Vũ Thị Thanh Lâm** (Ecole Polytechnique de Montréal, Canada)
The employee scheduling problem with short-term training skills

11:25 – 11:55 **Phong Thị Thu Huyền** (Viện Toán học)
A modified Graham's scan algorithm for finding smallest connected orthogonal convex hulls of a finite planar point set

Chủ nhật, ngày 3 tháng 5 năm 2020

Buổi tối

- Trực tuyến trên https://zoom.us/join, Meeting ID: 896-8339-8794, Password: 559118.

Chủ tọa: **Hà Minh Hoàng**

20:00 – 20:45 **Tạ Thúy Anh** (ORLab, Đại học Phenikaa)
Stochastic optimization of staffing for multiskill call centers

20:45 – 21:15 **Nguyễn Duy Thịnh** (Université de Montréal, Canada)
Visualizing and analyzing solution
for the locomotive assignment problem with distributed power

21:15 – 21:45 **Phạm Hoàng Giang** (Université de Montréal, Canada)
Solving locomotive routing problem by rolling horizon approach

21:45 – 21:55 **Giải lao**

21:45 – 22:25 **Đoàn Thanh Tân** (Đại học Nantes, Pháp)
The vehicle routing problem with relaxed priority rules

22:25 – 22:55 **Phạm Văn Cảnh** (ORLab, Đại học Phenikaa)
Influence maximization on socical graphs

TÓM TẮT BÁO CÁO

The most fundamental parts of convex analysis and its applications to optimization

Dương Thị Việt An[1]

Abstract. Convex optimization has an increasing impact on many areas of mathematics, applied sciences, and practical applications. It is now being taught at many universities and being used by researchers of different fields. As convex analysis is the mathematical foundation for convex optimization, having deep knowledge of convex analysis helps students and researchers apply its tools more effectively. The main goal of this presentation is to provide an easy access to the most fundamental parts of convex analysis and its applications to optimization. Modern techniques of variational analysis are employed to clarify and simplify some basic proofs in convex analysis and build the theory of generalized differentiation for convex functions and sets infinite dimensions.

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The min-cost parallel drone scheduling vehicle routing problem

Nguyễn Minh Anh[1], **Hà Minh Hoàng**[1]

Abstract. Adopting unmanned aerial vehicles (UAV), also known as drones, into the last-mile-delivery sector and having them worked alongside trucks with the aim of improving service quality and reducing the transportation cost gives rise to a new class of Vehicle Routing Problems (VRPs). In this talk, we introduce a new optimization problem called the min-cost Parallel Drone Scheduling Vehicle Routing Problem (PDSVRP). The objective is to minimize the total transportation costs including travelling costs incurred by trucks and drones embedded in a delivery system. We formulate this problem as a Mixed Integer Linear Programming and then develop a Ruin and Recreate (R&R) heuristic algorithm for the PDSVRP. Exploiting PDSVRP solution characteristics in an effective manner, the proposed R&R heuristic manages to introduce "sufficient" rooms to a solution via Adjacent String Removal and Sweep Removal during the ruin phase. It is expected to enhance the possibilities for improving solutions later in the recreate phase that greedily inserts with blinks removed customers. The results found in multiple experiments on a new set of randomly generated instances confirm the efficiency and consistency of our approach. To explore the benefits of drone delivery as well as the insight into the impact of related factors on the contribution of drones' use to operational cost, a sensitivity analysis is conducted. The results suggest that the battery capacity is the most important factor for drones to guarantee attractive benefit. Finally, we manage to adapt the proposed algorithm to solve the Parallel Drone Scheduling Traveling Salesman Problem (PDSTSP) with makespan objective and validate it via benchmarks available in the literature. It is shown that our metaheuristic is competitive to state-of-the-art algorithms. More remarkably, it finds 27 new best known solutions.

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Stochastic optimization of staffing for multiskill call centers

Tạ Thúy Anh[1]

Abstract. We study the staffing optimization problem in multiskill call centers, in which we aim at minimizing the operating cost while delivering a high quality of service (QoS) to customers. We introduce the use of chance constraints which require that the QoSs are met with a given probability. We consider staffing optimization problems in different settings and study the proposed models in both theoretical and practical aspects.

The talk is about three articles dealing with different challenges in modeling and solving staffing optimization problems in multiskill call centers. The first and second articles concern a two-stage staffing optimization problem under uncertainty. While in the first one, we study a general two-stage discrete stochastic programming model to provide a theoretical guarantee for the consistency of the sample average approximation (SAA) when the sample sizes go to infinity, the second one applies the SAA approach to solve the two-stage staffing optimization problem under arrival rate uncertainty. Both papers indicate the viability of the SAA approach in our context, in both theoretical and practical aspects.

In the last article, we consider problems with chance constraints on the service level measures. Our methodology proposed in this article is motivated by the fact that the QoS functions generally display "S-shape" curves and might be well approximated by appropriate sigmoid functions. Based on this idea, we develop a novel approach that combines non-linear regression, simulation and trust region local search to efficiently solve large-scale staffing problems in a viable way. The main advantage of the approach is that the optimization procedure can be formulated as a sequence of steps of performing simulation and solving linear programming models. Numerical results based on real-life call center examples show the practical viability of our approach.

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Influence maximization on social graphs

Phạm Văn Cảnh[1]

Abstract. Tối đa ảnh hưởng (Influence Maximization) là một trong những bài toán quan trọng trong lan truyền và điều khiển thông tin trên các mạng xã hội trực tuyến. Ngoài những giá trị to lớn của chúng trong thương mại cũng như lan truyền tiếp thị (viral marketing), tối đa ảnh hưởng còn có nhiều ứng dụng quan trọng khác như: ngăn chặn và điều khiển dịch bệnh (epidemics blocking and control), xác định nguồn ảnh hưởng (identify sources of information), hệ thống khuyến nghị (recommendation system), v.v. Tuy vậy, trong thực tế việc giải quyết bài toán tối đa ảnh hưởng gặp rất nhiều thách thức. Thách thức chính trong việc giải quyết bài toán này là nó thuộc lớp NP-Khó và việc tính toán hàm mục tiêu thuộc lớp bài toán #P-Khó. Trong báo cáo này, chúng tôi sẽ trình bày tổng quan về các thuật toán xấp xỉ, các ứng dụng và biến thể của bài toán tối đa ảnh hưởng.

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Ants can solve the parallel drone scheduling traveling salesman problem

Đỗ Đức Đông[1], **Đinh Quốc Trung**[2], **Hà Minh Hoàng**[2]

Abstract. In this talk, we are interested in studying the parallel drone scheduling traveling salesman problem (PDSTSP), where deliveries are split between a truck and a fleet of drones. The truck performs a common delivery tour, while the drones are constrained to perform back and forth trips between customers and a depot. The objective is to minimize the completion time coming back to the depot of all the vehicles. We present a hybrid ant colony optimization (HACO) metaheuristic to solve the problem. Our algorithm is based on an idea from the literature that represents a PDSTSP solution as a permutation of all customers. Then a dynamic programming is used to decompose the customer sequence into a tour for the truck and trips for the drones. We propose a new dynamic programming combined with other problem-tailored components to efficiently solve the problem. When applied to benchmark instances from the literature, our algorithm performs comparably to state-of-the-art algorithms and improves several new best known solutions.

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Solving locomotive routing problem by rolling horizon approach

Phạm Hoàng Giang[1], **Emma Frejinger**[1], **Jean-Francois Cordeau**[1]

Abstract. This talk addresses the locomotive routing problem arising at Canadian National Railway - the largest railway in Canada in terms of both revenue and the physical size of its rail network. The problem falls into the locomotive routing problem category because it aims to determine the sequence of activities operated by each locomotive over the planning horizon. We take into account maintenance requirements of locomotives, as well as other common railroad operations, such as sending locomotives among stations by deadheads and light travels and leasing of third-party locomotives. Based on the Mixed Integer Programming (MIP) formulation and the Time-Expanded Network represented in the literature, we introduce the Rolling Horizon Approach as an efficient method to find sub-optimal solutions in an acceptable computing time. Computational experiments on real-based instances show the pros and cons of our algorithm when compared with the exact MIP-based method.

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Improved results for the minimum distance superset problem

Nguyễn Minh Hải[1,2], **Nguyễn Ngọc Anh**[1], **Phạm Hương**[3], **Đỗ Đức Đông**[1], **Nguyễn Diệp**[2], **Hà Minh Hoàng**[3]

Abstract. Given a set D of positive integers - also called distances, the Minimum Distance Superset Problem (MDSP) requires for retrieving the position of minimum size set of points on the real line such that the pairwise distance between these points creates the superset of D. The problem has a number of applications in many fields such as X-ray crystallography and DNA structure reconstruction. In this talk, we provide better lower and upper bounds that help to solve the problem more efficiently by both approximate and exact methods. First, we propose an algorithm based on the Subset Sum Problem to reduce the size of MDSP instances by removing redundant distances. Second, we transform the problem into the integer set on the cyclic group that allows us to improve the lower bounds of the problem. Third, we propose two approaches to improve upper bounds: (i) we solve the MDSP on the coefficients of linear combination of distances on two mutually prime integers, and (ii) we implement a simple, yet efficient metaheuristic based on the idea of the Large Neighborhood Search (LNS). Finally, we discover a class of optimal solutions that can be used to significantly reduce the size of existing mixed integer programming models. Extensive computational experiments on benchmark instances show the performance of our methods, leading to new best solutions for the problem.

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The vehicle routing problem with synchronization constraints

Hà Minh Hoàng[1], **Nguyễn Tất Đạt**[1], **Nguyễn Duy Thịnh**[2], **Phạm Hoàng Giang**[2], **Đỗ Thị Minh Thúy**[2], **Louis-Martin Rousseau**[3]

Abstract. We consider a vehicle routing problem which seeks to minimize cost subject to time window and synchronization constraints. In this problem, the fleet of vehicles is categorized into regular and special vehicles. Some customers require both vehicles' services, whose starting service times at the customer are synchronized. Despite its important real-world application, this problem has rarely been studied in the literature. To solve the problem, we propose a Constraint Programming (CP) model and an Adaptive Large Neighborhood Search (ALNS) in which the design of insertion operators is based on solving linear programming (LP) models to check the insertion feasibility. A number of acceleration techniques is also proposed to significantly reduce the computational time. The computational experiments show that our new CP model finds better solutions than an existing CP-based ANLS, when used on small instances with 25 customers and with a much shorter running time. Our LP-based ALNS dominates the cp-ALNS, in terms of solution quality, when it provides solutions with better objective values, on average, for all instance classes. This demonstrates the advantage of using linear programming instead of constraint programming when dealing with a variant of vehicle routing problems with relatively tight constraints, which is often considered to be more favorable for CP-based methods.

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Affine minimax variational inequalities and two-person matrix games

Dương Thị Kim Huyền[1]

Abstract. The concept of minimax variational inequality was proposed in [2]. This talk establishes some properties of monotone affine minimax variational inequalities and gives sufficient conditions for their solution stability. Then, by transforming a two-person zero sum game in matrix form [1] to a monotone affine minimax variational inequality, we prove that the saddle point set in mixed strategies of the matrix game is a nonempty compact polyhedral convex set and it is locally upper Lipschitz everywhere when the game matrix is perturbed. The rate of convergence of the extragradient method of Korpelevich applied to the matrix game is also discussed.

References.

[1] E. N. Barron, *Game theory: An introduction (second edition)*, Wiley, 2013.

[2] N. Q. Huy and N. D. Yen, Minimax variational inequalities, *Acta Mathematica Vietnamica*, 36:265–281, 2011.

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A modified Graham's scan algorithm for finding smallest connected orthogonal convex hulls of a finite planar point set

Phan Thành An[1], **Phong Thị Thu Huyền**[1], **Nguyễn Thị Lê**[1]

Abstract. We introduce the concept of extreme points of a connected orthogonal convex hull of a planar point set, and show that these points belong to the given set. Then we prove that the construction of the smallest connected orthogonal convex hull of a finite set of points is an orthogonal (x, y)-polygon where its convex vertices are its connected orthogonal hull's extreme points. We then present an efficient algorithm, based on the idea of Graham's scan algorithm, for finding a connected orthogonal convex hull of a finite set of points. We also show that the lower bound of such algorithm is $\mathcal{O}(n \log n)$. Some numerical results for finding a connected orthogonal convex hull of a finite set of points are presented.

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Visual descriptions for solutions of some parametric optimal control problems

Vũ Thị Hướng[1], **Võ Đại Quý**[2]

Abstract. In this talk, we present visual descriptions for the change of solutions of three parametric optimal control problems in [1, 2] via illustrative figures or animations. The work will not only help the results in the just-cited papers become more complete, but also help such formal mathematical results reveal their beauty in a simple way.

References.

[1] V. T. Huong, J.-C. Yao, and N. D. Yen, Analyzing a maximum principle for finite horizon state constrained problems via parametric examples. Part 1: Unilateral state constraints, *Journal of Nonlinear Convex Analysis*, 21:157–182, 2020.

[2] V. T. Huong, J.-C. Yao, and N. D. Yen, Analyzing a maximum principle for finite horizon state constrained problems via parametric examples. Part 2: Bilateral state constraints, *preprint*, 2019.

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The employee scheduling problem with short-term training skills

Vũ Thị Thanh Lâm[1], **Marc-André Renaud**[1], **Louis-Martin Rousseau**[1], **Nadia Lahrichi**[1]

Abstract. Training is an important task that takes a significant part in the total operational cost of companies and organizations in multiple domains. Not only new recruits but also experienced employees must be trained with new skills, especially when there is a serious shortage of human resources. This is even more crucial today when the human is facing the global pandemic created by the COVID-19 virus with millions of infected people all around the world. Retired nurses and doctors, students from medical universities, and volunteers who have been mobilitied to work at hospitals, must be trained with different healthcare skills in a short time. In this talk, we study the employee scheduling problem in which we need to assign employees to training skills such that the number of tasks that have enough skilled employees is maximized satisfying different practical constraints. Mixed Integer Programming (MIP) models are first proposed to mathematically formulate the problem. Different heuristics are also proposed to provide solutions in a reasonable computation time. Experimental results obtained on randomly generated instances of different contexts are reported and analyzed.

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Online stochastic optimization of radiotherapy patient scheduling

Vũ Duy Mạnh[1], **Louis-Martin Rousseau**[1]

Abstract. The effective management of a cancer treatment facility for radiation therapy depends mainly on optimizing the use of linear accelerators. This research deals with scheduling patients on these machines taking into account types of patients, the maximum waiting time before the first treatment, and the utilization of resources on overtime. We collaborate with Centre Integrede Cancerologie de Lava (CICL), one of cancer treatment facilities in the Montreal region. Furthermore, we integrate the uncertainty related to the arrival of patients at the center. We develop two online optimization methods: a greedy strategy and a heuristic based on multiple generated scenarios to better meet the needs of central planning. Results based on randomly generated data show that our methods outperform the current policies typically used in treatment centers.

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The vehicle routing problem with relaxed priority rules

Đoàn Thanh Tân[1], **Nathalie Boste**[1], **Hà Minh Hoàng**[2]

Abstract. The Vehicle Routing Problem (VRP) is one of the most studied topics in Operations Research. Among the numerous variants of the VRP, this research addresses the VRP with relaxed priority rules in which customers are assigned to several priority groups and customers with the highest priorities typically need to be served before lower priority ones. We use additional rules to control the trade-off between priority and cost efficiency. This problem has flexible applications in the context of commercial logistics, as well as humanitarian relief operations. We propose a Mixed Integer Linear Programming (MILP) model to formulate the problem and to solve small-sized instances. An Adaptive Large Neighborhood Search (ALNS) algorithm with problem-tailored components is then designed to handle the problem at larger scales. The results demonstrate the robustness of the model and the performance of the proposed method.

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A binary linear programming approach for timetabling in Vietnamese schools

Lê Xuân Thanh[1], **Nguyễn Thị Nga**[1]

Abstract. In this talk, we propose a binary linear programming formulation for the timetabling problems in the context of Vietnamese schools. The formulation is capable of handling most school timetable constraints. We propose a method of linearizing binary-value functions in order to model some advanced constraints and objectives. This technique makes special features in our proposed formulation: we can minimize the number of idle times and the number of single-time teaching days of the teachers to obtain as compact timetables as possible. Numerical experiments on real-life instances are presented showing the efficiency of the proposed formulation.

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Joint chance-constrained staffing optimization in multi-skill call centers

Đàm Tiến Thành[1], **Tạ Thúy Anh**[1], **Mai Anh Tiến**[2], **Hà Minh Hoàng**[1]

Abstract. This talk concerns the staffing optimization problem in multiskill call centers. The objective is to find a minimal cost staffing solution while meeting a target level for the quality of service (QoS) to customers. We consider a staffing problem in which joint chance-constraints are imposed on the QoS of the day. Our joint chance-constrained formulation is more rational capturing the correlation between different call types, as compared to separate chance-constrained versions considered in previous studies. We show that, in general, the probability functions in the joint chance-constraints display S-shaped curves, and the optimal solutions should belong to the concave regions of the curves. Thus, we propose an approach combining a heuristic phase to identify solutions lying in the concave part and a simulation-based cut generation phase to create outer-approximations of the probability functions. This allows us to find good staffing solutions satisfying the joint chance-constraints by simulation and linear programming. We test our formulation and algorithm using call center examples of up to 65 call types and 89 agent groups, which shows the benefits of our joint-chance constrained version as compared to the separate one, and the advantage of our algorithm over standard ones.

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Fair and efficient resource allocation: computational complexity and algorithms

Nguyễn Trung Thành[1]

Abstract. Resource allocation with its wide range of important applications has a long research history. In this problem, finding an allocation that satisfies fairness and efficiency simultaneously is highly desired but computationally hard. We solve this problem approximately in polynomial time by modeling it as a bi-criteria optimization problem that can be solved efficiently by determining an approximate Pareto set of bounded size. We focus on two criteria: max-min fairness and utilitarian efficiency, and study this problem for the setting when there are only a few items or a few agents. We show in both cases that one can construct an approximate Pareto set in time polynomial in the input size, either by designing a dynamic programming scheme, or a linear-programming algorithm. Our techniques strengthen known methods and can be potentially applied to other notions of fairness and efficiency as well.

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Visualizing and analyzing solution for the locomotive assignment problem with distributed power

Nguyễn Duy Thịnh[1], **Emma Frejinger**[1], **Jean-Francois Cordeau**[1]

Abstract. One of the most important optimization problems faced in railway transportation is locomotive planning. In this talk, we study a general version of the locomotive assignment problem at the tactical level in which we consider several real-life aspects in the decision process. The visualization and scenario analysis are based on the solutions of the proposed method in [1]. We have performed our experiments based on 20 instances that mimic historical data provided by CN (Canadian National Railroad Company) which operates the largest rail network in Canada and the only transcontinental network in North America with over 20,000 miles of railroads. The rail network operated by CN has over 1,400 stations out of which roughly 350 appear as an origin or destination in a train of the schedule. A typical weekly train schedule has approximately 1,600 mainline trains and 4,000 in total.

References.

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Vehicle routing with transhipment facilities, time windows and time-dependent travel times on a road network

Đỗ Thị Minh Thúy[1], **Michel Gendreau**[1], **Jean-Yves Potvin**[1]

Abstract. In this talk, we introduce a novel vehicle routing problem in a road network that involves multiple vehicle types, transshipment points, time windows, and time-dependent travel speeds. This problem is motivated by a real life application in an urban context where customer demands are restricted to be delivered within a specific time range, and the travel time on a path between two locations may change during the day. The use of two types of vehicles with differences in many aspects such as capacity, speed and operating area makes the delivery process more flexible. Intermediate transshipment points, which have no physical capacity, are places where goods can be transferred between vehicles for delivery. To solve the problem, we first identify shortest paths between two customers by applying a time-dependent Dijkstra's algorithm. Then, based on the obtained paths, a tabu search is used to identify routes of minimum total duration.

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Robust multi-product pricing under general discrete choice models

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Abstract. We study robust versions of pricing problems where customers choose products according to a general extreme value (GEV) choice model, and the choice parameters are not given exactly but lie in an uncertainty set. We show that, when the robust problem is unconstrained and the price sensitivity parameters are homogeneous, the robust optimal prices have a constant markup over products, and we provide formulas that allow to compute this constant markup by binary search. We also show that, in the case that the price sensitivity parameters are only homogeneous in each subset of the products and the uncertainty set is rectangular, the robust problem can be converted into a deterministic pricing problem and the robust optimal prices have a constant markup in each subset, and we also provide explicit formulas to compute them.

For constrained pricing problems, we argue that the formulation where the aim is to find purchase probabilities that maximize the expected revenue while satisfying some expected sale constraints, even-though convenient to use when the choice parameters are exactly known, is not appropriate in our uncertainty setting, as there may be no fixed prices under which the resulting purchase probabilities always satisfy the expected sale constraints when the choice parameters vary in an uncertainty set. Thus, we propose an alternative formulation where, instead of requiring that the expected sale constraints be satisfied, we add a penalty cost to the objective function for violated constraints. We then show that the robust pricing problem with over- expected-sale penalties can be reformulated as a convex optimization program where the purchase probabilities are the decision variables. We provide numerical results for the logit and nested logit model to illustrate the advantages of our approach.

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