VeRoLog 2015

4th Meeting of the EURO Working Group on

Vehicle Routing and Logistics Optimization

Vienna, June 8-10, 2015

Exhibitors and Sponsors

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1.3 Local Organizing Committee

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Jakob Puchinger, Austrian Institute of Technology, Vienna

Carina Artner-Konecny, University of Vienna
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Petra Vogl, University of Vienna

The organizing committee as well as all volunteers can be identified by their light blue badges.

2 Conference Venue

The conference venue is the brand new building of the Faculty of Business, Economics and Statistics of the University of Vienna:

University of Vienna
Oskar-Morgenstern-Platz 1
1090 Vienna

This is an attractive location in close vicinity to the very city center. The location is

- close to public transportation: 5 minutes walk to metro line U4 (connecting e.g. to the City Air terminal, the opera, Schönbrunn castle) and 3 minutes walk to Tram D (passing along Ringstrasse and connecting two major trains stations)

- within easy walking distance to the city centre and most of the sights of Vienna

- right at the banks of the "Donaukanal" channel next to lots of pubs at the banks of the river/channel, a particularly pleasant place in summer.

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.

2.1 About Vienna

Vienna has a rich cultural scene and plenty of opportunities for recreation and outdoor life. Many of the tourist attractions and several hotels are within easy walking distance of the conference location. Vienna also has an excellent system of public transportation and all tourist attractions can easily be reached by subway or tram (e.g. Schönbrunn castle by subway U4 within 15 minutes).

Vienna is a very safe city: Mercer's Quality of Living Survey 2014 again ranked Vienna number one worldwide. For the last years ICCA (International Congress and Convention Association) has always ranked Vienna among the top three conference cities in the world.
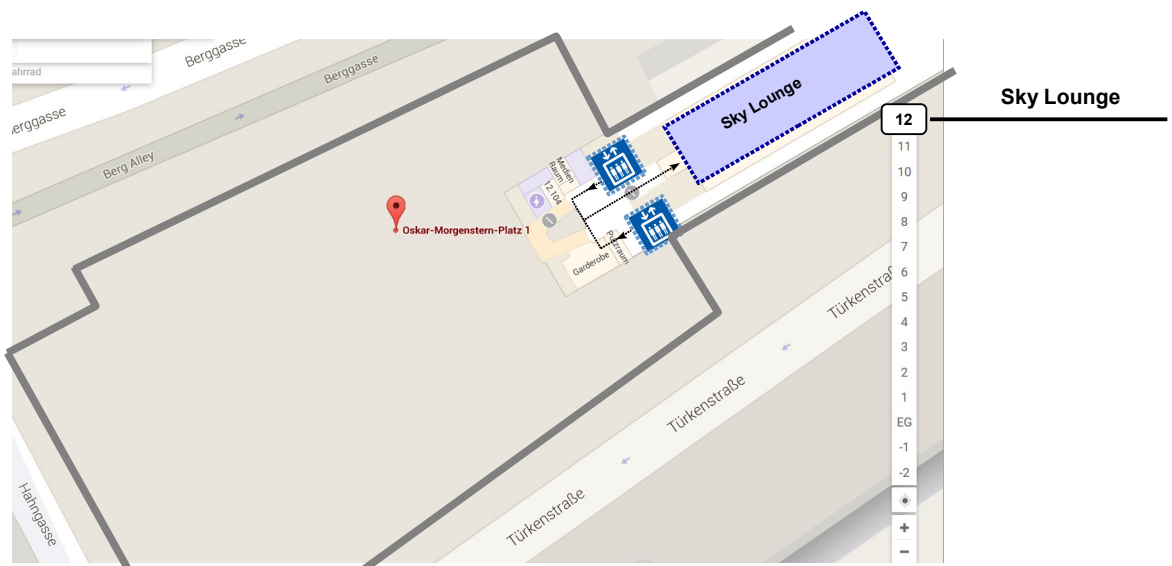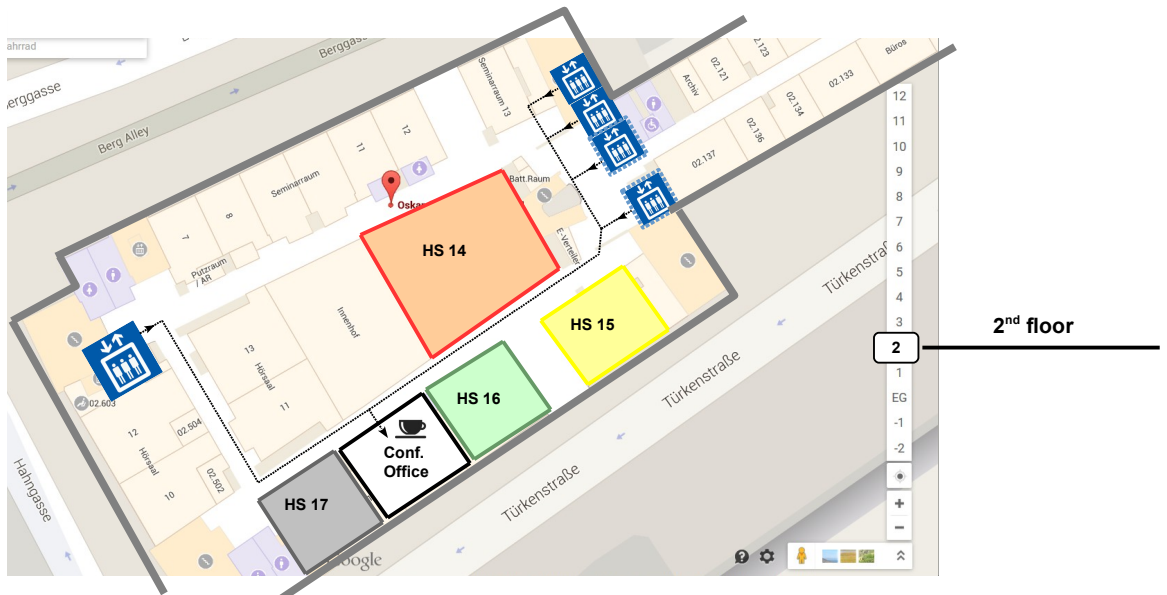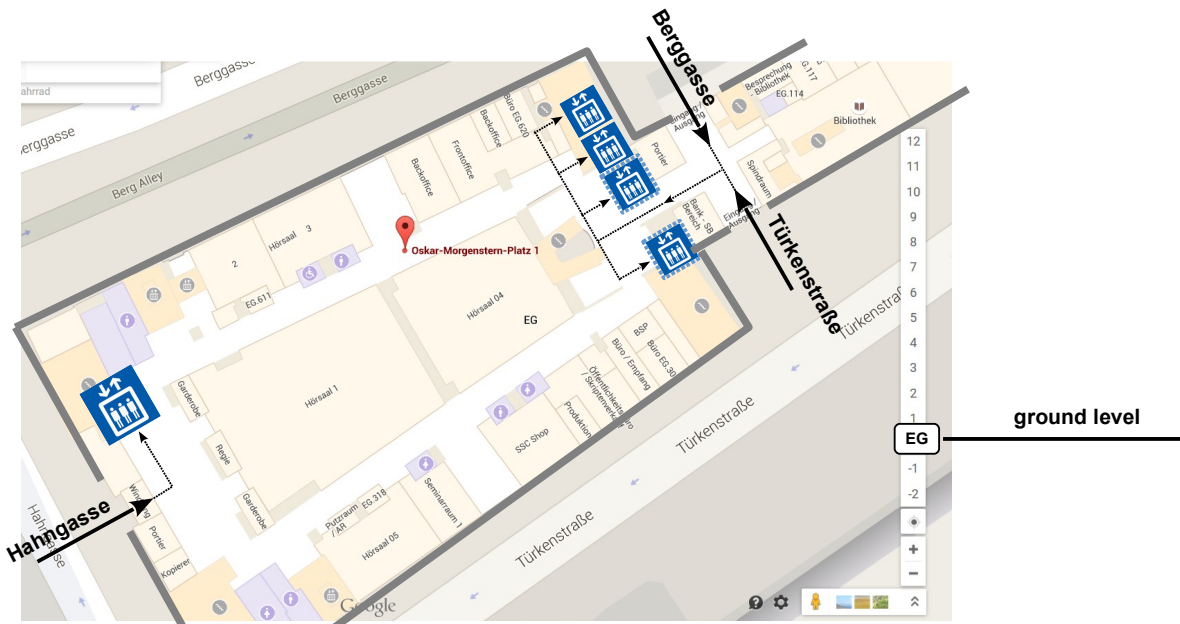
2.2 Plans

The easiest way to get to the conference venue is by U4, exit "Rossauerlände". Alternatively, one can take tram D until exit "Schlickgasse".

The building Oskar-Morgenstern-Platz 1 can be entered through 3 different ways: (1) entrance "Berggasse" when arriving with U4, (2) entrance "Türkenstraße" (opposite) and (3) entrance "Hahngasse" when arriving with tram D.

Most of the **conference rooms** are located in the **second floor** of the building. However, the room "**Sky Lounge**" is located in the **12th floor** of the building. This floor can only be reached with two elevators at the entrance Berggasse/Türkenstraße (see button "12" at the elevators).

Please find the floor plans of the conference venue Oskar-Morgenstern-Platz 1 below:

Berggasse
Berg Alley
Berggasse

Büro EG 620
Backoffice
Frontoffice
Pförtner

Besprechung
Bibliothek
EG.117
EG.114
Bibliothek

Hörsaal 3
2
EG.611
Oskar-Morgenstern-Platz 1

Hörsaal 04
EG
Bank SB
Bereich
Eingang
Ausgang
Einmündung
Ausgang
Spindraum

Garderobe
Hörsaal 1
BSP
Büro / Empfang
Öffentlichkeitsarbeit
Steigeraum
Produktion
SSC Shop

ground level

EG

Regie
Weg / Pförtner
Garderobe
Seminarraum 1
Türkenstraße
Putzraum / Aft EG.318
Hörsaal 05

Kopierer

Türkenstraße

Fahrrad
Berggasse
Berggasse

Seminarraum 13
Archiv
02.121
02.123
Büro
02.133
02.134
02.136
02.137

11
12
Seminarraum
Batt.Raum
Oskar...

7
8
HS 14
E.Verteiler

HS 15

2nd floor

2

02.603
13
Innenhof
HS 16

Conf. Office

12
02.504
Hörsaal 11
02.502

Hörsaal 10
HS 17

Türkenstraße

Hahngasse

Fahrrad
Berggasse
Berggasse
Berg Alley

Sky Lounge

Sky Lounge

12

Modem
Raum
12.104
Oskar-Morgenstern-Platz 1

Putzraum
Garderobe

Türkenstraße

Türkenstraße

Hahngasse

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3   Additional Information

3.1   General Information

Registration & Information Desk The Registration & Information Desk is situated in seminar room 14 (located between HS 16 and HS 17) and is open everyday from 08:30 until the end of the technical program. On Sunday, the Registration Desk is located in the Sky Lounge, where the Welcome Reception takes place.

Badges are required to access the lunch area as well as the buses for the excursion on Tuesday. However, we encourage all attendees to wear the badges at all sessions and events.

Coffee breaks Coffee, tea, beverages, fruits and snacks are served in seminar room 14 during the coffee breaks indicated in the Conference Program.

Lunch will be provided at Gasthaus Rebhuhn from 12:30 to 14:00 on Monday and Wednesday and from 13:00 to 14:30 on Tuesday. Please bring your conference badge to lunch! Gasthaus Rebhuhn is located 250 metres walking distance from the conference site in Berggasse 24 (see map below).

Internet Access WiFi is either available through your eduroam account or by a guest account provided in your welcome folder.

Viennese Public Transport The Viennese Public Transport System consists of 5 metro lines, various tram lines and buses. The metro lines operate from 05:00 to approximately 00:20. One can either buy single tickets (2.20 EUR), 24/48/72 hours tickets (7.60 EUR, 13.30 EUR, 16.50 EUR respectively) or weekly tickets (valid Monday 00:00 to successive Monday 09:00, 16.20 EUR). Additionally, the Vienna Card includes a 72 hours ticket and discounts for many sights, museums, concerts and more (price 21.90 EUR, see http://www.wien.info/en/travel-info/vienna-card)

City Bike You can rent a bike from one of over 100 stations in Vienna and discover the city per bike. The bike can be returned at any other station. Registration costs 1.00 EUR via Credit Card, the first hour of every ride is free. Other rates and more information online: www.citybikewien.at.

3.2   Speakers and Session Chair Information

How to find your session All sessions will be held in the Faculty building of Business, Economics and Statistics, Oskar-Morgenstern-Platz 1. Each session is identified with a code with the first letter indicating the day of the week (M→Monday, T→Tuesday, W→Wednesday) and the second letter indicating the time slot at the given day. The successive number is the room in which the session takes place (01→HS 14, 02→HS15, 03→HS16, 04→HS17, 05→Sky Lounge). See also the floor plan on page iii.

Audio-visual services All session rooms are equipped with a computer, with a WINDOWS 7 operating system and 4:3 format for the screen, and a projector with VGA or HDMI input. Please follow these guidelines to ensure a successful presentation.

Loading your presentation Please arrive to your session at least **15 minutes before it begins** to upload your presentation to the computer in the room. A volunteer or technical staff member will assist you. We encourage the speakers to bring a USB key with a copy of their presentation.

Presentation guidelines 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.

Assistance during your session In each session, one volunteer will be available to assist you with technical difficulties. Volunteers and staff members can easily be recognized by their light blue badge.

Session chair guidelines The role of the Chair is to coordinate the smooth running of the session and to introduce each speaker. The chair begins and ends the session on time. Please stick to the order of talks and times announced in the program and indicate the time to the presenter.

4 Program

Monday (8 June

	HS 14	HS 15	HS 16	HS 17	Sky Lounge
09:00 - 09:30	MA-1: Opening Welcome				
09:30 - 10:30	MB-1: Plenary: Savelsbergh				
coffee break					
11:00 - 12:30	MC-1: Exact Solution of VRPs 1	MC-2: Electric Vehicle Routing 1	MC-3: Health Care	MC-4: Stochastic and Time Dependent Vehicle Routing	MC-5: Packing & Routing 1
lunch break					
14:00 - 16:00	MD-1: Green VRPs 1	MD-2: Arc Routing	MD-3: Solver Challenge	MD-4: City Logistics 1	MD-5: Inventory Routing
coffee break					
16:30 - 18:00	ME-1: Rich VRPs 1	ME-2: Collaborative Vehicle Routing 1	ME-3: Synchronized Routing	ME-4: Pickup & Delivery 1	ME-5: Miscellaneous VRPs
18:00 - 18:30					
break					
19:30	**conference dinner (Vienna City Hall)**				

Tuesday (9 June)

	HS 14	HS 15	HS 16	HS 17	Sky Lounge
09:00 - 11:00	TA-1: City Logistics 2	TA-2: Bike Sharing	TA-3: Multi-Objective Routing	TA-4: Assignment Problems	TA-5: Rich VRPs 2
coffee break					
11:30 - 13:00	TB-1: VRPs with Profits	TB-2: Collaborative Vehicle Routing 2	TB-3: Exact Solution of VRPs 2	TB-4: Green VRPs 2	TB-5: Waste Collection Problems
lunch break					
14:30 - 15:30	TC-1: Plenary: Bektas				
break					
16:00	**excursion (Stift Klosterneuburg)**				
19:30	**dinner at a 'Heurigen' (Schübel Auer)**				

Wednesday (10 June)

	HS 14	HS 15	HS 16	HS 17
09:00 - 10:30	WA-1: Pickup & Delivery 2	WA-2: Packing & Routing 2	WA-3: Rich VRPs 3	WA-4: Urban Distribution
coffee break				
11:00 - 12:30	WB-1: Network Design	WB-2: Waterway VRP	WB-3: Exact Solution of VRPs 3	WB-4: Scheduling
lunch break				
14:00 - 15:30	WC-1: Rich VRPs 4	WC-2: Pickup & Delivery 3	WC-3: Dynamic VRPs	WC-4: Electric Vehicle Routing 2
break				
15:45 - 16:45	WD-1: Closing Session			
break				
17:00 – 18:30	WE-1: ELOCOT panel			
18:30	**farewell (Sky Lounge)**			

4.1 Social Program

4.1.1 Welcome Reception, Sunday 18:00, Sky Lounge

We kindly invite you to participate at the Welcome Reception, which takes place on Sunday, June 7th from 18:00 to 21:00 in the Sky Lounge at the University of Vienna, Oskar-Morgenstern-Platz 1, 12th floor.

4.1.2 Conference Dinner, Monday 19:30, Vienna City Hall

The Conference Gala Dinner will be held in the Vienna City Hall on invitation by the Mayor of Vienna City. Either take the underground line U2 (exit "Rathaus") or one of the tram lines that pass the City Hall (tram 1, 71, D, exit "Rathaus") to get to the City Hall. Please bring your invitation letter to the dinner (to be found in the conference bag)!

4.1.3 Excursion Klosterneuburg & Heuriger, Tuesday 16:00

Buses for the Conference Excursion depart at 16:00 in front of the conference venue (exit "Türkenstraße") – please do not forget to bring your excursion voucher (to be found in the conference bag).

Firstly, the excursion will stop at "Kahlenberg" which is located in the Vienna Woods and is one of the most popular viewpoints in Vienna. Afterwards, the bus takes the participants to Klosterneuburg, where three guided tours through the monastery are offered. Participants can either choose: (1) the Sacred Tour, (2) the Imperial Tour and (3) the Wine Cellar Tour (tour number was already chosen in the conference registration, http://www.stift-klosterneuburg.at/).

Finally, after a short bus ride, the participants will have traditional Viennese dinner at a Heurigen in Nussdorf (Heuriger Schübel-Auer, since 1711, Kahlenberger Straße 22, 1190 Vienna, http://www.schuebel-auer.at/). Individual return to the city centre using tram D, leading to the conference venue ("Schlick-gasse") and various other stops in the city centre (see plan below). Participants without a valid transport ticket for the Viennese Transport System may pick up a ticket for a single journey from a member of the organizing committee.
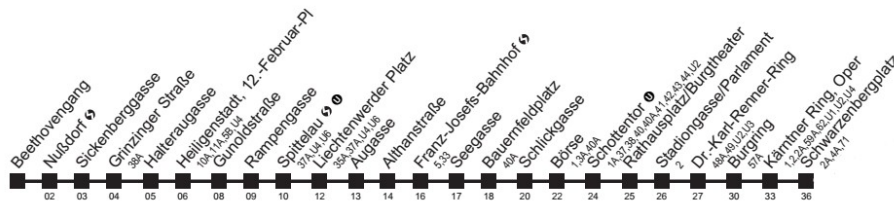
4.1.4 Farewell, Wednesday 18:30, Sky Lounge

Finally, after the ELOCOT panel discussion, a farewell event will take place in the Sky Lounge to close the VeRoLog 2015 (Wednesday, starting at 18:30).

4.2 Awards and Prices

VeRoLog 2015 Dissertation Award The VeRoLog 2015 Dissertation Award will be presented during the Opening Session MA-01 (Monday, 09:00-09:30, HS 14).

VeRoLog 2015 Solver Challenge The finalists of the VeRoLog 2015 Solver Challenge will present their work in session MD-03 (Monday, 14:00-16:00, HS 16). The winner of the Solver Challenge will be announced during the Closing Session WD-01 (Wednesday, 15:45-16:45, HS 14).

4.3 Technical Program

On the following pages, the Technical Program including the abstracts can be found.

Monday, 09:00-09:30

■ MA-01

Monday, 09:00-09:30 - HS 14

Opening Welcome

Stream: VEROLOG PLENARY
Chair: *Richard Hartl*

Monday, 09:30-10:30

■ MB-01

Monday, 09:30-10:30 - HS 14

Opening Plenary: Savelsbergh

Stream: VEROLOG PLENARY
Chair: *Richard Hartl*

1 - Supporting Innovations in Transportation: Research Opportunities
Martin Savelsbergh

Ever-increasing digital connectivity, automotive technology advances, and societal changes, have resulted in a proliferation of disruptive and innovative transportation services, for both passengers and freight. In this talk, we review some of these transportation services and highlight how they can lead to new, interesting, and challenging routing and scheduling problems.

Monday, 11:00-12:30

■ MC-01

Monday, 11:00-12:30 - HS 14

Exact Solution of VRPs 1

Stream: Exact Solution of VRPs
Chair: *Juan José Salazar González*

1 - Exact methods for solving the Carrier-Vehicle Traveling Salesman Problem (CVTSP)
Claudio Gambella, Andrea Lodi, Daniele Vigo

Carrier-vehicle systems generally consist of a slow carrier vehicle (e.g., a ship) with a long operating autonomy and a faster vehicle (e.g., an aircraft) with a limited operative range. The carrier has the property of transporting the faster vehicle and of deploying, recovering and servicing it. The goal of the Carrier-Vehicle Travelling Salesman Problem (CVTSP) is to make the faster vehicle visit a given collection of points in the shortest time while using the carrier vehicle as a base for possible multiple tours (e.g., rescue missions). As a consequence, carrier and vechile tours should be synchronized (see [1]). The present work focuses on the case in which the visiting sequence of the targets is not a priori given. Related problems on Carrier-Vehicle problems may be found in [2] and [3]. We present an exact formulation for CVTSP expressing the problem as a Second Order Conic Problem (SOCP). Computational results are shown for the resolution with appropriate commercial solvers such as MOSEK. The SOCP structure and the relationship to the Traveling Salesman Problem are exploited for builing a Benders fashion exact resolution algorithm which outperforms the commercial solvers resolution in the vast majority of the considered cases.

References: [1] M. Drexl: Synchronization in Vehicle Routing - A Survey of VRPs with Multiple Synchronization Constraints. Transportation Science 46(3): 297-316 (2012)

[2] E. Garone, R. Naldi, A. Casavola. A Traveling Salesman Problem for a Class of Carrier-Vehicle System, AIAA Journal of Guidance, Control, and Dynamics, Volume 34, No. 4, July—August 2011, pp. 1272-1276.

[3] E. Garone, J.-F. Determe, and R. Naldi. "Generalized Traveling Salesman Problem for Carrier-Vehicle Systems", Journal of Guidance, Control, and Dynamics, Vol. 37, No. 3 (2014), pp. 766-774.

2 - A new sparse transformation and exact algorithm for the Clustered Traveling Salesman Problem
Jens Lysgaard

The Clustered Traveling Salesman Problem (CTSP) is a variation of the Traveling Salesman Problem (TSP) in which the set of vertices has been partitioned into clusters, and with the requirement that the vertices in each cluster must be visited consecutively. Two interrelated sequencing problems are embedded in the CTSP. One problem is to determine the order of visit within the individual cluster, the other is to determine the ordering of clusters. This paper proposes a new transformation of the CTSP into an Equality Generalized Traveling Salesman Problem (E-GTSP), which is the problem of finding a minimum-cost circuit visiting exactly one vertex in each cluster. The transformation is sparse as a consequence of the E-GTSP containing only arcs between vertices in different clusters. An arc in the E-GTSP contains the implicit representation of a Hamiltonian path through a cluster in the CTSP, hence the calculation of arc costs in the E-GTSP may be time consuming. Instead of precalculating all arc costs in the E-GTSP, a novel characteristic of the proposed branch-and-cut algorithm is that costs of Hamiltonian paths through large clusters are calculated only as and when needed by the overall algorithm. Computational results are reported.

3 - Stronger Multi-Commodity Flow Formulations of the Capacitated Vehicle Routing Problem
Juan José Salazar González

The "Capacitated Vehicle Routing Problem" is a much-studied (and strongly NP-hard) combinatorial optimization problem, for which many integer programming formulations have been proposed. We present two new "multi-commodity flow" (MCF) formulations, and show that they dominate all of the existing ones, in the sense that their continuous relaxations yield stronger lower bounds. Moreover, we show that the relaxations can be strengthened, in pseudo-polynomial

time, in such a way that all of the so-called "knapsack large multistar" (KLM) inequalities are satisfied. The only other relaxation known to satisfy the KLM inequalities, based on set partitioning, is strongly NP-hard to solve. Computational results demonstrate that the new MCF relaxations are significantly stronger than the previously known ones.

This talk is based on a paper recently accepted for publication in EJOR.

■ MC-02

Monday, 11:00-12:30 - HS 15

Electric Vehicle Routing 1

Stream: Electric Vehicle Routing Problems
Chair: *Mario Ruthmair*

1 - The Hybrid Vehicle Routing Problem
Simona Mancini

In this paper the Hybrid Vehicle Routing Problem (HVRP) is introduced and formalized. This problem is an extension of the classical VRP in which vehicles can work both electrically and with traditional fuel. The vehicle may change propulsion mode at anytime. Unitary travel cost is much lower for distances covered in the electric mode. Electric battery has a limited capacity and may be recharged at a recharging station (RS). A limited number of RS is available. Once a battery has been completely consumed the vehicle automatically shift to traditional fuel propulsion mode. Further a maximum route duration is imposed according to drivers contracts regulations. A Mixed Integer Linear Programming formulation is presented and a Large Neighborhood Search based Matheuristic is proposed. The algorithm consist into, starting from an initial solution, destroying, at each iteration, a small number of routes, letting unvaried the other ones, and reconstructing a new feasible solution running the model on only the subset of customers involved in the destroyed routes. This procedure allows to exhaustively explore a large neighborhood within very short computational time. Computational test showing the performances of the matheuristic are presented. The method has been tested also on a simplified version of the HVRP already presented in the literature, the Green Vehicle Routing Problem (GVRP), obtaining very good results. Finally, some consideration about the effect of subsidies to promote the use of the electric propulsion system, is analyzed and discussed.

2 - Mixed Integer Programming Models for Hybrid Electric Vehicle Routing
Christopher Bacher, Günther Raidl

Recently the subfield of "Green Vehicle/Pollution Routing Problems" (G-VRP/PRP) arose, which incorporate fuel consumption and environmental considerations into traditional VRPs. So far, models for these VRPs consider conventional and pure electric vehicles only. We extend these approaches for Hybrid Electric Vehicles (HEVs) by providing mean-velocity mixed integer formulations for HEV G-VRPs, which is — if HEV specific features are modelled — a far from trivial task. Hybrid electric powertrains rise in popularity for both passenger and light duty vehicles, as their combination of an electric drive with a combustion engine can lower fuel consumption and pollutant emission. This is achieved by operating the HEV in different modes, which determine the currently active machines. For HEV G-VRPs not only the optimal route is sought, but also the according operation strategy determining the distribution of the energy requirements on the different operation modes. We focus on parallel hybrids, a common technical realization of HEVs, and show in a first model that the operational complexity cannot be captured by a MIP in a computationally feasible way. Therefore we currently seek for reductions of this complexity s.t. routes are unlikely to change by incorporating more information into the model and provide approaches how such reductions can be checked. Reduced models are not only beneficial for MIP formulations but also for heuristic approaches by speeding up solution evaluation.

3 - Models for Electric Vehicle Routing Problems with Load-Dependent Energy Consumption
Mario Ruthmair, Luís Gouveia, Jakob Puchinger, Daniel Rebelo dos Santos

We study generalizations of classical vehicle routing problems: Instead of vehicles with a conventional combustion engine we consider electric vehicles which usually have a strictly limited range. We assume that these vehicles might not be able to complete their tour with a single battery charge and thus would have to visit one or more recharging stations. Given is a graph with a depot, a set of clients, and a set of

recharging stations. Each client has a strictly positive demand. In the simplest problem variant a vehicle's state of charge (SOC) is fully recovered when visiting a charging station. A network arc is defined by its travel cost, the energy consumed by an empty vehicle, and the additional energy when carrying a single load unit. Based on these values the total consumed energy on this arc depending on the current vehicle's load can be derived. These energy values can be negative if the vehicle is able to recover energy on a downward slope. The fleet is homogeneous with fixed load and SOC limits. The objective is to find a set of routes with minimal total costs such that each route starts and ends at the depot, each client is visited exactly once, the total demand of all clients on a route must not exceed the load capacity, and the SOC stays within its limits. Recharging stations may be visited as often as necessary. We consider special variants with a single vehicle and/or with strictly positive energy values. In an extended variant we also include the time dimension, i.e., travel times, customer time windows, and variable charging times. We present flow-based mixed integer linear programming formulations and corresponding branch-and-cut methods to solve them.

■ MC-03

Monday, 11:00-12:30 - HS 16

Health Care and Humanitarian Logistics

Stream: Health Care and Humanitarian Logistics
Chair: *Walter Gutjahr*

1 - A bi-objective home care scheduling problem: Analyzing the trade-off between costs and client inconvenience

Kris Braekers, Richard Hartl, Sophie Parragh, Fabien Tricoire

Organizations providing home care services are inclined to optimize their activities in order to meet the constantly increasing demand for home care. In this context, home care providers are confronted with multiple, often conflicting, objectives such as minimizing their operating costs while maximizing the service level offered to their clients by taking into account their preferences. This paper sheds some light on the trade-off relationship between these two objectives by modeling the home care routing and scheduling problem as a bi-objective problem. The proposed model accounts for qualifications, working regulations and overtime costs of the nurses, travel costs depending on the mode of transportation, hard time windows, and client preferences on visit times and nurses. A distinguishing characteristic of the problem is that the scheduling problem for a single route is a bi-objective problem in itself, thereby complicating the problem considerably. A metaheuristic algorithm, embedding a Large Neighborhood Search heuristic in a Multi-Directional Local Search framework, is proposed to the solve the problem. Computational experiments on a set of benchmark instances based on real-life data are presented. A comparison with exact solutions on small instances shows that the algorithm performs well. An analysis of the results reveals that service providers face a considerable trade-off between costs and client convenience. However, starting from a minimum cost solution, the average service level offered to the clients may already be improved drastically with limited additional costs.

2 - A Variant of Vehicle Routing Problem in Blood Supply Chain

Ali Ekici, Okan Ozener

In this paper, we study the routing of collection vehicles in blood supply chain. In order to extract platelets, donated blood has to be processed at a central processing facility within six hours of donation time. Blood collection organizations have to dispatch collection vehicles and schedule pickups from the donation sites so that the donated units can be used in platelet production. We analyze the routing decisions in such a setting and propose an integrated clustering and routing framework to collect and process maximum number of donations for platelet production.

3 - The Humanitarian Pickup and Distribution Problem

Michal Tzur, Ohad Eisenhandler

Food rescue operation is the collection of perishable products from food suppliers who are willing to make donations and their distribution to welfare agencies that serve individuals in need. This activity has become increasingly widespread in recent years due to economic crises that have increased the demand for nutritional aid. It is also beneficial to donors (food suppliers) who can avoid in this way the costs of destroying excess production while reflecting a social-aware image. The problem we study, the Humanitarian Pickup and Distribution Problem, focuses on the logistic challenges of a food bank coordinating this operation on a daily basis. The operation is performed using vehicles with limited capacity whose travel time cannot exceed an imposed maximal duration, defined by the driver's working hour regulations. We model this operation as a routing—allocation problem, with the aim of maintaining equitable allocations to the different agencies in each period, while delivering as much as possible in total. We present and discuss the chosen objective function, which promotes effectiveness and equity. We show how these two measures can be combined in a way that satisfies desired properties of the allocation, that is easy to compute and implement within a mathematical formulation, and that balances effectiveness and equity acceptably. We present characteristics of an optimal solution to the problem, an efficient algorithm to solve the allocation sub-problem, as well as exact and heuristic approaches to solve the problem. Results of case studies based on real data are presented.

4 - Modelling Beneficiaries' Choice in Disaster Relief Logistics

Christian Burkart, Pamela Nolz, Walter Gutjahr

In this presentation, location-routing models for disaster relief logistics are enriched by considering beneficiaries' choices of distribution centers (DCs). The proposed models are well suited for decision support systems.

Managers in humanitarian logistics have to decide where to establish DCs for relief goods and how to supply the DCs by delivery tours. The proposed bi-objective location-routing model minimizes two objectives. The first objective is unserved demand, resulting from two sources: lost demand by insufficient attractiveness or prohibitive distance of opened DCs (this is described by means of an elastic demand function), and demand that cannot be fulfilled due to limited capacities at the DCs. The second objective, cost, includes the costs for opening and running DCs and for routing the relief goods.

The model anticipates the choice of beneficiaries whether and to which DC to go for getting supply, based on a model adopted from the literature on competitive location analysis (Drezner and Drezner 2012). A mathematical programming formulation is presented and used within the context of an epsilon constraint method to determine the Pareto front for small instances. Realistic instances cannot be solved exactly by this approach, so an evolutionary algorithm has been implemented as well. The test instances are derived from the Gaza region in southern Mozambique. The results show that when designing a distribution network, improvements can be achieved by taking the predicted behavior of beneficiaries into account.

■ MC-04

Monday, 11:00-12:30 - HS 17

Stochastic and Time Dependent Vehicle Routing

Stream: Stochastic and Time Dependent Routing
Chair: *Dirk Christian Mattfeld*

1 - An Anticipatory Rollout Algorithm for a Vehicle Routing Problem with Stochastic Customer Requests

Marlin Wolf Ulmer, Dirk Christian Mattfeld, Marco Hennig

In the considered vehicle routing problem, a vehicle has to serve customers requesting service during the day. The tour starts in a depot, where the vehicle has to return within a given time limit. A set of known early request customers has to be served. During the day, stochastic new customers request service. The dispatcher has to decide about confirming or rejecting each request. Decisions are permanent and have to be made immediately after the request appears. Objective is a high service level and hence, to maximize the number of confirmations.

For this problem, anticipation of future requests is mandatory for effective decision making. Previous research shows that approaches sampling future requests are able to explicitly anticipate possible new customer requests over a highly limited time horizon resulting in detailed short-term anticipation. Methods of approximate dynamic programming (ADP) allow more general long-term anticipation, but require aggregation of problem information to a limited set of parameters. Customers are considered only implicitly.

To combine the advantages of both approaches, we define a rollout algorithm (RA). RA maximizes the immediate and expected confirmations using a markov decision process (MDP). To reduce complexity, later decisions in the MDP are selected by a base heuristic. For this problem, the vast set of possible outcomes is reduced to an efficient set of stochastic paths by sampling. We apply ADP as base heuristic. Computational studies show that RA allows detailed long-term anticipation achieving significantly better results compared to the already high quality solutions of the single approaches.

2 - Time Dependent Traveling Salesman Problem with Time Windows: Properties and an Exact Algorithm
Emanuela Guerriero, Gianpaolo Ghiani, Anna Arigliano, Antonio Grieco

In this paper, we deal with the Time-Dependent Traveling Salesman Problem with Time Windows (TDTSPTW). Firstly, we prove that under special conditions the TDTSPTW can be solved as an Asymmetric Traveling Salesman Problem with Time Windows (ATSPTW), with suitable-defined time windows and (constant) travel times. Secondly, we show that, if the special conditions do not hold, the ATSPTW optimal solution provides both a lower bound and (eventually) an upper bound with a worst-case guarantee for the original TDTSPTW. Finally an integer linear programming model is presented and valid inequalities are embedded into a branch-and-cut algorithm. Computational results show that the proposed algorithm is able to solve instances with up to 40 vertices.

3 - A multicommodity and multimodal service network design problem with uncertain travel times
Emrah Demir, Wolfgang Burgholzer, Martin Hrusovsky, Emel Arıkan, Werner Jammernegg, Tom Van Woensel

The growing specialization and internalization of the world trade has lead to increasing distances between suppliers, producers and the final customers. This development resulted in the increasing volumes of global transportation operations during the last decades. The number of efficient transportation solutions to this change can be increased by using different transportation modes (e.g., road, rail, and maritime) and combining them in multimodal transportation chains.

Intermodal container transportation offers a fast alternative to unimodal transportation by road especially for long distances and, therefore, its volume has been growing significantly over the last decade. The complexity of transportation plans lies in the use of multi transportation modes and uncertainty in travel times and demands. In addition, constraints (e.g., fixed time schedules and routes, transhipment, sequence of transportation services, etc.) need to be considered in the transport planning phase.

In response to the above-mentioned complexities, this talk presents a stochastic mixed-integer linear programming formulation based approach for an advanced intermodal transportation planning problem on a transportation network including different transportation modes and transhipment locations. The aim of the research is to generate optimal and robust transportation plans using the intermodal transportation network. Capacity, travel and service times as well as costs and greenhouse gases (GHGs) of each specific transport service (i.e., truck, train or barge) are also taken into account. Moreover, the proposed methodology allows planners to optimize their transportation plans according to different objectives (i.e., cost, time and GHG emissions) and considers uncertainties connected with travel times.

■ MC-05
Monday, 11:00-12:30 - Sky Lounge

Packing & Routing 1

Stream: Packing & Routing
Chair: *Jean-François Côté*

1 - A matheheuristic algorithm for the vehicle routing problem with container loading constraints
David Álvarez Martínez, Luis Miguel Escobar Falcón, John Willmer Escobar

This paper presents a matheheuristic algorithm for solving the capacitated vehicle routing problem with practical three-dimensional loading constraint. This problem is known as 3L-CVRP (Capacitated Vehicle Routing Problem and Container Loading Problem). The proposed methodology consists of two phases. The first phase uses an optimization procedure based on cuts to obtain solutions of the capacitated vehicle routing problem. The second phase validates the solutions of the first phase by a GRASP algorithm (Greedy Randomized Adaptive Search Procedure). In particular, the GRASP approach considers the packing problem for each route. The former algorithm uses a Lagrangean relaxation of the classical model of two-sub index for the vehicle routing problem and different types of cuts (subtour elimination, capacity constraint cuts, and packing constrains cuts). The proposed algorithm is compared with the most effective approaches for the 3L-CVRP on a subset of benchmark instances considered in the literature. The computational results show that the proposed approach is able to obtain good solutions improving some of the best-known solutions from the literature.

2 - The Vehicle Routing Problem with Simultaneous Pick-Ups and Deliveries and Two-Dimensional Loading Constraints
Emmanouil Zachariadis, Christos Tarantilis, Chris Kiranoudis

We introduce and solve the Vehicle Routing Problem with Simultaneous Pick-ups and Deliveries and Two-Dimensional Loading Constraints (2L-SPD). 2L-SPD covers cases where customers raise both delivery and pick-up transportation requests. These requests call for transporting rectangular items which are not stackable. 2L-SPD belongs to the class of composite routing-packing problems. However, it is the first such problem to consider bi-directional material flows from and to a central distribution center, dictated in practice by reverse logistics policies. The aspect of jointly satisfying delivery and pick-up orders has a major impact on the loading requirements of the model: feasible loading patterns for the transported items must be identified for every arc travelled in the routing plan. To solve the 2L-SPD model, we propose a local search framework for the routing aspects employing a packing heuristic procedure for identifying feasible loading arrangements for the items onboard. Loading feasibility memorization techniques are used for accelerating the proposed methodology. To assess the performance of the proposed routing and packing algorithmic components, we have solved the well-known Vehicle routing Problem with Two-Dimensional Constraints (2L-CVRP). Our algorithm produces 2L-CVRP results of fine quality improving several best known solution scores. Results are also reported on newly constructed 2L-SPD benchmark problems which involve up to 255 customers and 786 transported items. Finally, 2L-SPD solutions are compared against other routing alternatives to gain insight of the cost savings achieved by simultaneously offering pick-up and delivery service.

3 - A parallel heuristic for the two-dimensional capacitated vehicle routing problem
Jean-François Côté, Leandro Coelho

In this talk we present a high performing heuristic to solve the two-dimensional capacitated vehicle routing problem (2L-CVRP). This problem is a practical extension of the well known VRP, in which customer demands consist of a certain number of two-dimensional items. Each item is characterized by its weight, and its length and width dimensions, such that all items packed into a truck must respect its weight capacity and must fit its dimensions without overlapping. This variant of the VRP is significantly harder than the classical CVRP in the sense that it combines a packing problem and a vehicle routing problem. Two cases are typically studied in the 2L-CVRP, namely the sequential loading (2L-VRP-SL) and the unrestricted case (2L-VRP-UN). In the 2L-VRP-SL, another practical aspect is taken into account and the items in a truck must be packed in such a way that unloading the items for each customer in the route can be done without moving other items. This allows for the direct use of forklifts and saves time upon deliveries. In the 2L-VRP-UN, rearrangements of the items inside the truck are allowed.

We propose a new parallel algorithmic framework that is based on iteratively generating variables (as in a column-generation procedure), by validating some of columns, and by solving a set covering problem to select columns to be active in the final solution. The remaining columns are validated only if they are selected by the set covering layer. Specifically, we create vehicle routes, we validate their packing in parallel according to several lower bound, heuristic and exact methods, and we solve the set covering problem over the columns that were not discarded. Our methods are capable of improving the best known solutions from the literature and to prove optimality or reduce the gap with respect to the lower bounds.

Monday, 14:00-16:00

■ MD-01

Monday, 14:00-16:00 - HS 14

Green VRPs 1

Stream: Green VRPs
Chair: *Richard Eglese*

1 - Vehicle Routing to Minimize Time-Dependent Emissions in Urban Areas

Jan Fabian Ehmke, Ann Campbell, Barrett Thomas

The reduction of emissions from heavy-duty trucks has become an important part of worldwide efforts to reduce CO2 emissions. This presentation focuses on the problem of minimizing CO2 emissions in the routing of vehicles in urban areas. In urban areas, we assume that the vehicle must travel at the speed of traffic, which is both variable and time-dependent. Visiting multiple stops over the course of a day, each customer has a pickup of a particular weight, and as a result, the weight of the vehicle changes as pickups are made. The emissions-minimizing path between any two customers can vary due to the impact of time-dependent speeds as well as the load on the vehicle. Thus, the best path between each pair of customers cannot as a rule be precomputed as in most vehicle routing problems which creates computational challenges.

To solve the problem, we adapt an existing tabu search algorithm for the vehicle routing problem with time-dependent travel times. We take advantage of an analytical result that allows us to precompute many of the required paths between customers. In the cases where we cannot precompute the paths, we solve a time-dependent, deterministic minimum emissions cost path problem while constructing routes. We test our approach with instances derived from a real road network and experiment with different numbers of vehicles, vehicle weights, and customer pickup quantities. Savings of up to 20% in emissions can be achieved when minimizing emissions for suburban customers compared to time-dependent travel time optimized tours.

2 - The fleet size and mix pollution-routing problem

Çağrı Koç, Tolga Bektas, Ola Jabali, Gilbert Laporte

This paper introduces the fleet size and mix pollution-routing problem which extends the pollution-routing problem by considering a heterogeneous vehicle fleet. The main objective is to minimize the sum of vehicle fixed costs and routing cost, where the latter can be defined with respect to the cost of fuel and CO2 emissions, and driver cost. Solving this problem poses several methodological challenges. To this end, we have developed a powerful metaheuristic which was successfully applied to a large pool of realistic benchmark instances. Several analyses were conducted to shed light on the trade-offs between various performance indicators, including capacity utilization, fuel and emissions and costs pertaining to vehicle acquisition, fuel consumption and drivers. The analyses also quantify the benefits of using a heterogeneous fleet over a homogeneous one.

3 - Environmental sustainability in logistics — the contribution from vehicle routing

Richard Eglese

Environmental sustainability is an area of concern for the transportation of goods. Negative environmental effects in logistics may arise from issues concerning such things as noise and safety, but this review will concentrate on Greenhouse Gas (GHG) emissions that result from logistic activities.

The models that are used to estimate the GHG emissions for road vehicles will be presented and compared to show the inputs that are needed and the outputs they provide.

Various approaches that use these models to plan vehicle routes will be compared, particularly considering whether time-independent or time-dependent models are used and whether the speed of the vehicles is regarded as fixed or variable within the models.

The scale of reduction in GHG emissions that is achievable through the adoption of vehicle routing systems will be examined and compared to the effect on GHG emissions from other factors such as the type and capacity of the vehicles used and the opportunities for backhauls and collaboration.

4 - The green vehicle routing and scheduling problem with time-varying traffic congestions

Abdullah Konak, Yiyong Xiao

We present a linear mixed integer programming model for the time-dependent heterogeneous vehicle routing and scheduling problem with the objective of minimizing total carbon dioxide emissions (TD-VRSP-CO2) in urban/suburban areas where road travel speeds are dictated by traffic rules and/or congestion. The proposed mathematical model uses the traveled distances of arcs in different time periods as decision variables to determine the travel schedules of vehicles. Thereby, heterogeneous vehicle types and general time-dependent traffic conditions can be used in the model. We propose an exact dynamic programming method to calculate the optimal discrete departure/arriving time for the TD-VRSP-CO2. The dynamic programming method significantly reduces the computational complexity of the TD-VRSP-CO2 when applying existing heuristic algorithms to solve large-sized problems. A genetic algorithm with dynamic programming (GA-DP) is developed to solve the formulated problem. Computational experiments are carried out to study the efficiency of the proposed hybrid solution approach with promising results.

■ MD-02

Monday, 14:00-16:00 - HS 15

Arc Routing

Stream: Arc Routing
Chair: *Bruce Golden*

1 - Compact Routes for the Min-Max K Windy Rural Postman Problem

Oliver Lum, Carmine Cerrone, Bruce Golden, Edward Wasil

In practice, it is often desirable for the routes of vehicles to exhibit certain properties that are not included in the objective function. Two such properties are compactness and separation. A set of routes is compact if the streets serviced by each route are geographically clustered, and separated if the routes overlap minimally. We consider the Min-Max K Windy Rural Postman Problem (MMKWRPP), in which the objective is to route a fleet of K homogeneous vehicles such that the cost of the longest route is minimized. We develop a heuristic that is algorithmically simple, produces solutions that are comparable in quality to those produced by existing approaches, and performs well with respect to metrics that quantify compactness and separation. Our heuristic uses a partitioning scheme in which a node's weight includes contributions from both incident streets requiring service and the distance needed to travel to a node. We present computational results for a set of instances that we generate from real-world street networks and for a set of artificial instances. Our code is part of the Open-source Arc Routing Library (OAR Lib) at https://github.com/Olibear/ArcRoutingLibrary .

2 - On the Prize-Collecting Windy Rural Postman Problem

Isaac Plana, Thais Ávila, Angel Corberan, Jose Maria Sanchis

Consider an undirected and connected graph. Associated with each edge, there are two costs corresponding to its traversal in each direction. In addition, some of the edges also have an associated prize that is collected the first time the edge is traversed. The Prize-Collecting Windy Rural Postman Problem consists of finding a closed walk starting and ending at the depot that maximizes the sum of the collected prizes minus the traversal costs. Here we present a formulation of this problem, some polyhedral results, and a branch-and-cut algorithm that is capable of solving randomly generated large-size instances.

3 - On the Collaboration Uncapacitated Arc Routing Problem

Dario Fontana, Elena Fernandez, M. Grazia Speranza

This paper introduces a new arc routing problem for the optimization of a collaboration scheme among carriers. This yields to the study of a profitable uncapacitated arc routing problem with multiple depots, where carriers collaborate to improve the profit gained. In the first model the goal is the maximization of the total profit of the coalition of carriers, independently of the individual profit of each carrier. Then, a lower bound on the individual profit of each carrier is included. This lower bound may represent the profit of the carrier in the case no collaboration is implemented. The models are formulated as integer linear

programs and solved through a branch-and-cut algorithm. Theoretical results, concerning the computational complexity, the impact of collaboration on profit and a game theoretical perspective, are provided. The models are tested on a total of 962 instances generated from 118 benchmark instances for the Privatized Rural Postman problem, with up to 102 vertices and 203 arcs. Out of the 962 instances, 952 were solved to optimality within 6 hours. Instances with up to 50 vertices were solved in few seconds.

4 - New flow models for arc routing
Cândida Mourão, Luís Gouveia, Leonor S.Pinto

The purpose of this work is to present a new flow based formulation for the Mixed Capacitated Arc Routing Problem (MCARP), following our previous work on a compact flow based model which led us to promising results. In particular, for a group of benchmark instances, the model provides the optimum for small to medium sized instances and produces good lower bounds for larger ones. The new model is obtained by disaggregating the set of flow variables in the previous model by link type, required and deadheading. This disaggregation allows us to create new inequalities that might strengthen the lower bounds. We will report computational experiments evaluating the trade-off between the new bounds and the increase in the number of variables. The motivation for the study is a household refuse collection problem in a municipality in Portugal that basically fits on a mixed capacitated arc routing problem (MCARP). Acknowledgement: Project partially supported by National Funding from FCT (PTDC/ECE-GES/121406).

■ MD-03
Monday, 14:00-16:00 - HS 16

Solver Challenge

Stream: Solver Challenge
Chair: *Daniele Vigo*

1 - Local Search for Forests and Trees in Combinatorial Optimization — A contribution to the Coach Trip with Shuttle Service Problem of the VeRoLog Solver Challenge 2015
Martin Josef Geiger

The talk presents a local search approach for the VeRoLog Solver Challenge 2015. In this competition, a variant of a bus routing problem is introduced that had to be solved under running time restrictions. The problem basically consists in transporting passengers from bus stops to a central hub, by means of either coaches or smaller shuttle vehicles. For the identification of a best-possible solution, a combination of Variable Neighborhood Search and Iterated Local Search has been put to work. Our ideas are based on the observation that any alternative can be represented by a forest of trees. It is therefore crucial to fast manipulate trees, or their components such as branches, respectively. Tests on the competition benchmark instances are presented and discussed.

2 - A framework for vehicle routing: an application for the VRP with Coach Trips and Shuttle Services (CTSSP)
Vladimir Deineko, Maksym Deineko

We consider the capacitated vehicle routing problem (VRP) and various modifications of this problem. We suggest a general framework which is flexible enough to be used for many modifications of the VRP. The main idea behind the framework is based on the well-known Held & Karp dynamic programming algorithm for the travelling salesman problem. In this presentation we discuss an application of this approach for the Verolog 2015 challenge problem.

3 - An improved Tabu Search heuristic Algorithm for the Coach Trip with Shuttle Service Problem
Oualid Guemri, Abdelghani Bekrar

In this work we present a Tabu Search (TS) heuristic algorithm for the Coach Trip with Shuttle Service Problem (CTSSP). The CTSSP, which is a personal-transportation problem, consists of the collection of passengers from their origin stop to a final hub; this is done using some coaches and additional shuttle vehicles if needed. To solve the CTSSP, we develop a TS method. First, the initial solution is generated using

Greedy Insertion Technique. Then, at each iteration, our TS generate the current solution neighborhoods using several operators. During the research, we use a repair heuristic in order to improve the overall cost. To evaluate the performance of our algorithm, 4 test instances are used. On average, the TS reports results with a gap of 5.01 % to the best known solution. Regarding this results, the improved TS is successfully qualified to the final round by the international challenge jury.

■ MD-04
Monday, 14:00-16:00 - HS 17

City Logistics 1

Stream: City Logistics
Chair: *Rune Larsen*

1 - Benefits of a cooperation between traffic management and city logistics
Felix Köster, Marlin Wolf Ulmer, Dirk Christian Mattfeld

The significant growth of urban traffic has led to road congestion in most cities worldwide. Courier, express and parcel (CEP) services are confronted with limited road infrastructure capacities in their delivery tours. The stochastic travel times need to be considered in decision making to achieve cost efficient routing. City traffic flows are controlled by traffic management (TM). TM uses infrastructure settings considering the observed traffic situations and calculated traffic forecasts. Controlling actions are, for example, the change of timing for traffic control lights or the imposition of speed limits. These actions are mainly combined to strategies and influence traffic flows and travel. The strategies need to be considered by CEP for routing decision making. In this presentation, we look into the benefits of a cooperative traffic management that communicates the current traffic strategy to a CEP provider. In particular, we look at the effects of different communication levels on the routing efficiency. In an exemplary dynamic vehicle routing problem with stochastic travel times, a CEP provider has to deliver parcels within a city network with stochastic travel times. Travel times are correlated and depend on the applied strategy of TM. To solve this problem, we introduce an Approximate Dynamic Programming (ADP) approach. This also allows anticipation of the traffic situations and TM actions. To show the effectiveness of the algorithms, we compare the results to a static MIP approach and a minimax-regret heuristic.

2 - Stochastic and dynamic city logistics
Rune Larsen

As urbanization continues worldwide, the growth of the cities results in increased congestion and contention for sparse road resources. The increased density of shops, one-way traffic, lacking parking space, traffic congestion, etc. serve to make the distribution of goods harder. The potential for consolidation is demonstrable using traffic counts, and urban consolidation centers have already been established in multiple cities.

To make urban consolidation profitable, the transshipment costs needs to be offset. This can be done using value added services such as packaging waste retrieval shortly after deliveries, increased punctuality, parcel pickup with same day delivery, etc. Solving the vehicle routing problem (VRP) with the value added services in an area with frequent traffic congestions and disruptions, becomes a highly dynamic and stochastic problem.

Real life map data is obtained using Open Street Maps, and Monte Carlo simulation is used to assess the robustness of (the unexecuted part of) the VRP. If the solution degenerates due to disruptions, or events (such as new orders) occur, the solution is updated using a heuristic solver for deterministic instances. The deterministic instance(s) to be solved are specifically crafted to result in robust solutions balanced against efficiency, and the process can be applied iteratively or in parallel to increase the likelihood of obtaining good solutions.

We demonstrate that the addition of certain constraints to the VRP, increases the sensitivity to disruptions. We also demonstrate that the expected impact of the disruptions can be minimized using carefully tailored instances, generated based on critical path methods.

3 - Exact formulations and algorithm for the Multi-depot Fleet Size and Mix Vehicle Routing Problem
Rahma Lahyani, Leandro Coelho, Jacques Renaud

In this paper we model and solve a complex variant of the vehicle routing problem called the Multi-depot Fleet Size and Mix Vehicle Routing Problem (MDFSMVRP). This problem involves many decisions such as the assignment of customers to depots and the selection of vehicle types and vehicles routes. These decisions yield a difficult optimization problem in which the objective is to find a fleet composition for each depot and a corresponding routing plan that minimizes the sum of routing and vehicle costs. We propose four mixed-integer linear programming formulations for the MDFSMVRP. We derive and introduce known and valid inequalities in all models. We then describe a branch-and-cut algorithm applicable for all formulations. We assess the performance of the algorithm on various instances from the literature including up to 360 customers and 9 depots. We provide lower and upper bounds and we present a computational comparison of all linear formulations in terms of the instance sizes and solution quality.

4 - Interval Travel Times for Reliable Routing in City Logistics
Patrick-Oliver Groß, Marlin Wolf Ulmer, Dirk Christian Mattfeld

Due to varying traffic volumes and limited traffic infrastructure in urban areas, travel times are uncertain and differ during the day. To ensure cost-efficient routing while satisfying promised delivery dates, information on expected travel times between customers needs to be exploited. We propose the usage of interval travel times (ITT) to enable cost-efficient and reliable routing in urban areas. ITT define a best-case and a worst-case travel time. ITT can be derived with relatively low effort due to low data requirements and straightforward calculation methods. We present and discuss the process of deriving ITT. Further, we extend an existing exact approach from the domain of robust planning and modify it to the requirements of routing in urban areas. As exact solution methods are not applicable for problem instances of realistic size, we develop a heuristic solution approach. The heuristic approach focuses on reducing the search space of tours that have to be examined by the robust planning approach. The results are evaluated in contrast to deterministic and stochastic approaches. Further, the trade-off between cost-efficiency and reliability of routes is discussed. Computational experiments show, how the incorporation of ITT leads to reliable and efficient routes.

■ MD-05

Monday, 14:00-16:00 - Sky Lounge

Inventory Routing

Stream: Inventory Routing
Chair: *Claudia Archetti*

1 - Modeling and solving an inventory-routing problem with stock outs for the automated teller machines
Homero Larrain, Leandro Coelho

The inventoryrouting problem (IRP) combines two wellknown problems in a multiperiod time horizon: vehicle routing and inventory management. In this problem a decision maker has to determine when to visit each costumer, how much to deliver each time, and how to arrange the costumers to be visited into different routes. The objective in the general case of the problem is to minimize the total inventory handling costs and the distribution costs jointly, while serving the demand in a satisfactory way. Inspired by real-life data and an industrial partner arising in the automated teller machine (ATM) industry, we study an IRP variant where stock outs are allowed. Our industry partner, from the city of Santiago, Chile, is in charge of the replenishment of some ATMs located throughout the city. Their goal is to replenish ATMs such that the forecasted demand can be satisfied. Stockouts are allowed, but the operator has to pay a fine for the demand that is lost while the machines are out of stock. The set of decisions involve defining replenishment days and quantities, as well as the routing of the vehicles throughout the serviced ATMs. In this research we develop an ad-hoc exact branchandcut algorithm for the IRP in which stock outs are allowed, to be capable of handle the case study proposed by our partner. We solve a mixed integer linear problem implementing a branch-and-cut algorithm in C++ using CPLEX Concert. The

subtour elimination constraints are originally relaxed, and then added dynamically when they are found to be violated during the iterations of the algorithm. This algorithm is capable of proving optimality for instances containing up to 15 nodes and 6 planning periods, and high quality solutions are obtained for larger instances using a preprocessing phase based on clustering procedures. Our solutions will be compared directly against the current solution employed by our partner.

2 - Min–Max Policies in the Robust Inventory Routing Problem with Transportation Procurement
Demetrio Laganà, Luca Bertazzi, Adamo Bosco

In the Inventory Routing Problem with Transportation Procurement, one supplier has to make decisions on when and how much to deliver to a set of retailers over a given planning horizon. The supplier has a limited production capacity at each time period. Deliveries are performed by using an outsourced feet of vehicles. We study the case in which the demand of the retailers is not known a priori and the probability distribution of the demand is not given as well, referred to as the Robust Inventory Routing Problem with Transportation Procurement. Our aim is to determine an optimal Min-Max policy (i.e. a policy that minimizes the maximum cost), to compare it with the classical optimal Min-Expected Value policy (i.e. a policy that minimizes the expected cost) and to propose a Min-Max Matheuristic algorithm (i.e. a heuristic algorithm in which Mixed-Integer Linear Programming Models are optimally solved) to find a near-optimal Min-Max policy for the solution of realistic size problem instances.

3 - Combined use of simulation and optimization models as a decision support tool for robust inventory routing problems
Jacek Kaleta, Pawel Hanczar, Marek Karkula

The combination of decisions regarding inventory management and vehicle routing decision leads to complex combinatorial optimization problem called the Inventory Routing Problem (IRP). Several heuristic algorithms for solving IRP were proposed in recent years. A lot of those proposals are based on static and deterministic versions of IRP. Based on our management experience we identified a lot of situations where the VMI approach is used but the dynamic version of the IRP has to be considered. Such situations occur in case of LPG and fuel supplies to fuel stations. There are some proposals of heuristic policies which can be used in above mentionned circumstances. While the advantage of stochastic information is used in heuristic rules, we based on information which is as current as possible. In our proposal after each delivery the optimization models are applied in order to optimize routes and delivery dates. In our paper we presented the combined use of optimization models and discrete event simulation to evaluate the influence of different variability of selected models' parameters on final plan. Simulation models have proved very useful as an aid to build dynamic and robust plans for considered inventory routing problem. We presented results of extensive simulation analysis of randomly generated cases for comparison our proposals and some policy solutions. Among other it is showed that for some values of parameters such as forecast errors and distribution system structure we can propose better solutions.

Monday, 16:30-18:30

■ ME-01

Monday, 16:30-18:30 - HS 14

Rich VRPs 1

Stream: Rich VRPs
Chair: *Geir Hasle*

1 - Sequential and parallel large neighborhood search algorithms for the periodic location routing problem
Vera Hemmelmayr

In this talk we present a large neighborhood search algorithm (LNS) to solve the periodic location routing problem (PLRP). The PLRP combines location and routing decisions over a planning horizon in which customers require visits according to a given frequency and the specific visit days can be chosen. Solving location and routing decisions simultaneously is particularly appealing in problems where these two decisions are on the same decision level or when the depot costs can be broken down to the considered planning horizon. Location routing problems are also interesting from a strategic point of view where building detailed routes can give a better approximation of future routing costs. Decomposition schemes that exploit the hierarchical nature of the problem are examined. Moreover, we use parallelization strategies that can exploit the availability of multiple processors. The simple methodology proposed can be easily applied to other problems and algorithms. Computational results show that our algorithm outperforms previous solution methods in terms of solution quality. We can show that for standard benchmark instances from the literature, improvements are possible both in the average solution quality as well as in the quality of best known solutions found.

2 - The Mixed Capacitated General Routing Problem - A Survey
Geir Hasle

In the VRP literature, there is almost a dichotomy between arc and node routing. In real life, there are several applications where a pure node routing or a pure arc routing formulation is not adequate. This talk will motivate, define, and describe the Mixed Capacitated General Routing Problem (MCGRP), also called the Node, Edge, and Arc Routing Problem (NEARP) which is a generalization of the CARP and the CVRP. The relatively scarce literature on the MCGRP and variants will be summarized, with focus on recent results, including work on the MCGRP with route balancing.

3 - Periodic Location Routing Problem: An Application of Mobile Health Services in Rural Areas
Sinem Savaser, Bahar Yetis Kara, Hunkar Toyoglu

In today's world, health services provided to the people living in rural areas are significant. Since primary and preventive healthcare centers are not that common in these areas, a system that has been called "mobile health services' is developed. In this system, family physicians are responsible for travelling the villages at specific times and frequencies and providing primary healthcare services in Turkey since 2010. The aim of this study is to decide on the locations of the origin hospitals and generate cost efficient service schedules for mobile family physicians. Because of the certain requirements of the Ministry of Health, this problem turns out to be a periodic location routing problem (PLRP). Research on the PLRP is limited and it has been only considered since 2007. The common characteristic of all existing studies in the periodic vehicle routing problem (PVRP) and PLRP literature is that the schedules are fixed. However, in this study, it is aimed to generate optimal periodic schedules for each doctor with a mathematical model. To the best of the authors' knowledge, no such study exist in the PVRP or PLRP literature, thus, we developed a new mathematical model which decides on the locations of the hospitals, assigns each village to dedicated doctors, fixes the time intervals between the visits and creates a periodic schedule for each doctor. The details of the model and the solution performances over real life data sets are going to be discussed during the presentation.

4 - The Demand- Selective Location Routing Problem: the School Districting Application
Bahar Yetis Kara, Nazlı Esen, Imdat Kara

In Turkey, eight years primary education is obligatory[1]. However, in some districts, there aren't any school. Thus, in order to provide education services for these children, the government runs the school districting program. In this program, these children are transported, free of charge, by the governmental busses to "close' districts with appropriate schools. From OR perspective, the school districting problem involves the decisions of selecting the central school(s) and finding the bus routes to carry the children to central schools. This problem structure is very similar to the well-known location routing problem.[2][3] One main difference is that in LRP, all demand points must be served where as in school districting application, depending on the location of the central school and districts, some districts will not be visited by the bus tour. In this paper, we provide mathematical models and heuristic approaches for minimizing the cost of school districting application. This paper contributes to the literature by presenting the new problem of school districting which is called demand-selective location routing problem.

References [1] The Turkish Constitution, 2012. Retrieved April 01, 2012 from http://www.tbmm.gov.tr/anayasa.htm. [2] Nagy, G., Salhi, S., 2007. Location-routing: Issues, models and methods. European Journal of Operational Research 177, 649-672. [3] Min, H., Jayaraman, V., Srivastava, R., 1998. Combined location-routing problems: A synthesis and future research directions. European Journal of Operations Research 108, 1-15.

■ ME-02

Monday, 16:30-18:30 - HS 15

Collaborative Vehicle Routing 1

Stream: Collaborative Vehicle Routing
Chair: *Martin Savelsbergh*

1 - Approaches for a Carrier's Bid Generation Problem in a Combinatorial Transport Auction
Tobias Buer

To support a freight carrier in a combinatorial transport auction, an exact and two heuristic strategies for bidding on subsets of requests are proposed. The exact bidding strategy is based on the concept of elementary request combinations. We show that it is sufficient and necessary for a carrier to bid on each elementary request combination in order to guarantee the same result as bidding on each element of the powerset of the set of tendered requests. Both heuristic bidding strategies identify promising request combinations. For this, pairwise synergies based on saving values as well as the capacitated p-median problem are used. The bidding strategies are evaluated by a computational study that simulates an auction. It is based on 174 benchmark instances and therefore easily extendable by other researchers. On average, the two heuristic strategies achieve 91 percent and 81 percent of the available sales potential while generating 36 and only 4 percent of the bundle bids of the exact strategy. Therefore, the proposed bidding strategies help a carrier to increase her chance to win and at the same time reduce the computational burden to participate in a combinatorial transport auction.

2 - A multi-objective collaborative approach for the vehicle routing problem with time windows
Christof Defryn, Kenneth Sörensen

The vehicle routing problem with time windows (VRPTW) is an extension of the classical vehicle routing problem where a time window interval is specified for every client. In this work, the VRPTW is extended by embedding it in a collaborative environment, where clients of different partners can be served by a shared fleet of vehicles. This approach gives rise to additional issues. First, there is the multi-objective character of the problem. Besides the total distance minimization, also the time window violations should be minimized. Contrary to the distance traveled, which is shared by the entire coalition, the time window violations may be different for every collaborating partner. For a coalition of N partners, the problem should therefore be solved for N+1 objectives. To achieve this, a multi-directional variable neighborhood search, which solves this problem without ranking or weighing the objectives in advance, is developed by the authors. The obtained result is a Pareto-front of non-dominated solutions. Second, the collaborative environment requires that a cost allocation method is embedded within our solution method. In this way, the total coalition cost can be allocated to the individual partners, which allows for giving incentives and rewarding flexibility. The Shapley Value allocation method is selected, as this is considered a relevant method both in academics and industry. The inclusion of such a cost allocation method

however is not straightforward, as it requires information on all possible sub-coalitions of the grand coalition. Because every sub-coalition is represented by a Pareto frontier and not by a single solution, the complexity of the problem increases significantly. By taking the partner's strategy (their attitude towards flexibility and therefore their allowance of time window violations) as a reference, the appropriate sub-coalition cost can be calculated. Results of this approach will be presented extensively during the presentation.

3 - A ridematching model with incentives

Mitja Štiglic, Niels Agatz, Martin Savelsbergh, Miro Gradisar

We consider a ridesharing system that allows people with similar itineraries and time schedules to share rides. Drivers are willing to somewhat extend or delay their original trips to accommodate riders searching for rides. We study different schemes to stimulate drivers and riders to increase their time flexibility so as to obtain solutions with a high matching rate. This is important for the sustainability of the system. We incorporate different types of incentives into the ride-matching model and also allow matches that do not have positive distance savings. We study how successful these strategies are in assuring a high matching rate and what is the opportunity cost of using them in terms of total driving distance savings and revenues to the ridesharing system provider.

■ ME-03

Monday, 16:30-18:30 - HS 16

Synchronized Routing

Stream: Synchronized Routing
Chair: *Jörn Schönberger*

1 - Solving a full truckload pickup and delivery problem with resource synchronization with an adaptive large neighborhood search algorithm

Axel Grimault, Nathalie Bostel, Fabien Lehuédé

In the public works sector, materials have to be transported between sites for road building and leveling works. Road infrastructure operations, in particular asphalt laying, involve using a large fleet of trucks to supply the application of asphalt concrete without discontinuance. Others transportations, like supplying in gravel a central, are more flexible with respect to time windows at collection or delivery locations.

To handle these transportations, vehicles travel large distances between collection and delivery sites. As only full truckload are involved, one objective is the minimization of empty travels. In addition, some transport requests may share a site where trucks are served by a single resource machine (i.e. a loader). The vehicles that serve these requests have to be synchronized on this resource.

We introduce the full truckload pickup and delivery problem with resource synchronization (FTPDP-RS) which concerns the routing and the scheduling on resources of a fleet of heterogeneous vehicles subject to temporal constraints. This problem is solved with an Adaptive Large Neighborhood Search (ALNS) algorithm. It integrates destroy and repair operators based on the literature and problem specific operators. To deal with precedences between nodes on routes and resources, we propose timing algorithms to efficiently evaluate the feasibility of insertions. The method is evaluated on instances from a real case study.

2 - Route Feasibility Testing and Forward Time Slack for Routing Problems with Temporal Intra-Route Synchronization Constraints

Timo Gschwind

We consider the Vehicle Routing Problem with Time Windows and Temporal Synchronized Pickup and Delivery (VRPTWTSPD) which is the prototypical routing problem with temporal intra-route synchronization constraints. It consists of finding a set of minimum-cost routes servicing transportation requests from pickup to delivery locations. The temporal synchronization constraints require that after completing the service at a pickup node, the corresponding delivery has to be performed within prespecified minimum and maximum time lags. In the presence of time-lag constraints, deciding whether or not a given route is feasible is a non-trivial task. Efficient feasibility testing of routes, however, is a crucial part in many exact and heuristic algorithms for routing problems. In this talk we present two different route

feasibility checks for the VRPTWTSPD by adapting the approaches of Tang et al. (2010) and Firat and Woeginger (2011) for the Dial-a-Ride Problem. The ability to quickly evaluate the feasibility of insertions of single nodes or requests into a given (feasible) route is another crucial aspect for some solution approaches. The concept of Forward Time Slack (FTS), originally introduced by Savelsbergh (1992) for the Vehicle Routing Problem with Time Windows, can be a useful tool for this kind of evaluation. We generalize the FTS to the VRPTWTSPD and detail why the definition of the FTS is less clear for problems with maximum time-lag constraints.

3 - Memetic Algorithm Approach for the 2-CVRP-S

Jörn Schönberger

We investigate a metaheuristic approach for the two-commodity capacitated vehicle routing problem with synchronization (2-CVRP-S). In the 2-CVRP-S customers must be supplied with two different commodities. Each commodity requires the assignment of a certain commodity-specific vehicle-type. A schedule synchronization constraint couples the two resulting vehicle routing problems for the two commodities at each customer location. This constraint ensures that the two delivery operations start times comply with given temporal restrictions. A memetic algorithm is proposed for solving 2-CVRP-S-instances. The memetic algorithm coordinates different local hill climbers.

■ ME-04

Monday, 16:30-18:30 - HS 17

Pickup & Delivery 1

Stream: Pickup & Delivery
Chair: *Sophie Parragh*

1 - Evaluation of Solution Methods for Single Vehicle Routing Problems

Thomas Wensing

An important element of many logistics systems is the routing of vehicles through a set of locations requiring service. The nature of the service can be very different. It may only involve a physical visit by the vehicle but can, for example, also include picking up or delivering materials. Planning such operations can be regarded as independent problem for a single vehicle on a pre-selected set of service jobs or as sub-problem of routing a fleet of multiple vehicles that can be employed to fulfil the service tasks. In its full problem scope we study the problem of planning multi-commodity pickup and delivery operations for a capacity-restricted vehicle, where the service jobs may exhibit precedence constraints and multiple optional time windows within which they can be fulfilled. The solution approach combines several methods of construction, perturbation, recombination and local search that have been proposed in the literature on the Traveling Salesman Problem and its relevant extensions. A major challenge is to support a variety of problems within one framework while remaining competitive with specialized algorithms. We study the performance of the implemented methods and their contribution to finding good solutions on basis of three sets of problems with different application background. The first set considers the combined pickup and delivery of finished vehicles, the second set is focused on finished vehicle delivery with varying dealership opening hours, the third set is concerned with assigning incoming trucks to multiple gates on a logistics yard.

2 - School Taxi Routing for Special Education Pupils in Germany

Zhi Yuan, Armin Fügenschuh, Anke Stieber

In Germany, the government is responsible for transporting pupils to schools. Different from deploying school buses to transport general education pupils at certain prescribed bus-stops, special education pupils (SEP, e.g. with disabilities) usually need to be transported door-to-door from home to school by taxis. The SEP usually travels a much longer distance to one of the few schools of their needs, and may require special designed space on the taxi for different types of wheelchairs. There exist ca. a hundred types of taxis differing in price (basic price + cost per km), passenger capacity from 2 to 28 persons, and wheelchair capacity from 0 to 4. Each taxi can be simultaneously shared by multiple pupils, and even pupils from different schools. Each pupil should arrive at their school 5 to 15 minutes before their class starts, and the journey should not exceed their maximum tolerable driving time. The objective is to save cost (thus tax money), while reducing emissions. This problem can be regarded as an extension of Heterogeneous VRP

with pickup and delivery and coupled time windows, and can be modelled as a multi-commodity flow problem either in a time-expanded network or using the Miller-Tucker-Zemlin formulation. However, the resulting MILP models can be solved to proven optimality by commercial solvers (e.g. CPLEX, Gurobi) only up to 10 pupils and 3 schools. To tackle this problem, a parameterized greedy (PGreedy) metaheuristic is developed, which applies a parameterized greedy criterion for node insertion, and the greedy parameters are automatically adapted during the algorithm run. PGreedy is tested on real-world instances up to 696 pupils and 53 schools. It has improved a current manual schedule by ca. 20%, and has also outperformed a commercial software with a genetic algorithm implementation specially designed for this task. Initializing commercial MILP solvers by the PGreedy solution further improves the best-found solution as well as the lower bound.

3 - Heuristics for the split-demand one-commodity pickup-and-delivery travelling salesman problem
Beatriz Santos-Hernández, Hipólito Hernández-Pérez, Juan José Salazar González

The Split-Demand one-Commodity Pickup-and-Delivery Travelling Salesman Problem (SD1PDTSP) merges the Capacitated Vehicle Routing Problem (VRP), the Split Delivery Vehicle Routing Problem (SDVRP) and the Pickup-and-Delivery problems in the following problem. A finite set of locations is given and the travel cost from one location to another location is assumed to be known. One specific location is considered to be a depot and the other locations are identified as customers. Each customer requires or provides a given demand of a single commodity (the product). A product unit collected from a pickup location can be supplied to any delivery location. It is assumed that there is a vehicle with a given capacity, originally at the depot, to serve the demands of all customers through a route. A route is a set of trips that cover each customer at least once. While following the route, the vehicle can either deliver or collect product in each location. All the visits to a customer must end up with exactly its required demand. The number of times that the vehicle visits a customer is limited by a given parameter m. Therefore the aim is to find a min-cost route for the capacitated vehicle such that it satisfies the demand of all customers.

An exact method has been studied for the SD1PDTSP which is able to solve to optimality instances with up to 30 customers. In this work we present heuristic methods based on neighborhood search, whose computational results have shown it is able to solve instances with up to 200 customers.

■ ME-05

Monday, 16:30-18:30 - Sky Lounge

Miscellaneous VRPs

Stream: Miscellaneous VRPs
Chair: *Michael Schilde*

1 - A Problem-Based Learning Activity to Teach VRP
Alex Grasas, Helena Ramalhinho Lourenco

This paper presents a problem-based learning (PBL) activity that uses a decision support system (DSS) to teach one of the most fundamental topics in distribution planning: vehicle routing. This pedagogical activity, employed in a logistics and supply chain management course, also seeks to create awareness among students on the importance of DSS for complex problems. The paper is written as a teaching guide for other instructors, detailing how the activity may be carried out in class.

In the proposed PBL activity, students are given a typical vehicle routing case to solve in teams. With no previous theoretical background taught on distribution planning, they need to find the best possible routes. After a week, a debriefing takes place in class with the professor, where different solutions, methodologies applied and problems encountered during the activity are discussed. The activity is supported by an open web-based tool that solves the problem using the popular Clarke and Wright Savings algorithm.

PBL is a teaching strategy that involves students from the very beginning, challenging them to solve a rather complicated problem similar to what they may find in their professional careers. Only when struggling with the difficulties of the case proposed, students really appreciate the potential value of DSS to make better decisions. Moreover, this activity raises concern about how DSS must be adapted for implementation in every particular business scenario.

2 - Cluster-First-Route-Second: Adapting the Cluster-First Part to Variable Requirements
Nitin Ahuja, Matthias Bender, Stefan Hacker

During VeRoLog 2014 we presented a cluster-first-route-second-approach for solving rich VRPs. The focus of our talk was on partitioning the given customers in appropriately balanced clusters, as it is often done in real world applications. Such an approach leads to better tours, satisfied field personnel, and happy customers. This year we present some extensions of our previous work with emphasis on reacting to changing scenarios. A typical example being the addition of new and/or deletion of a few old customers. In such a case, producing radically different clusters is rarely beneficial, because it leads to a major reorientation of staff and customers. A much better solution is one that keeps reassignments as well as concessions on good qualities of the original partition to a minimum. We show how this can be done efficiently by manipulating our partitioning model. We also present some results obtained by applying our methods to practical instances.

3 - Rolling Stock Allocation for Scheduled Railway Services
Sundaravalli Narayanaswami

Passenger railway transportation services in the Indian Railways are planned and published as timetables in advance. Most of these services are cyclic with a 24-hour periodicity for Suburban (within city) services and of a week or longer duration periodicity for long distance trains. To operate these services, train units (also known as rakes), human operators, tracks and platforms are assigned to each service and are allocated for specified time duration. Multiple constraints are involved in such resource allocations; some of the constraints are technical for safe operations and others are based on system performance improvement by effective and efficient utilization of all resources. Effective utilization requires that all services be accomplished without any shortage of resources and efficient utilization infers to optimal utilization of available resources. Given a set of resources, the objective of the model proposed in this paper is to optimally allocate the resources for specific time duration so that all transportation services can be accomplished. We have developed a heuristics based rake allocation model for a particular section of the Indian Railways and we have also proposed a set of evaluation measures for our model. Certain assumptions are made in an attempt to develop a simplified approach to solving a complex problem. Results of resource allocation and limitations of our model are also presented.

4 - Global management of containers in a multi-terminal, multi-modal port at the tactical level
Xavier Schepler, Stefan Balev, Sophie Michel, Eric Sanlaville

In the worldwide transport network, container ports act as intermodal interfaces, where containers are transferred between mother vessels, feeder vessels, river barges, trains and trucks. Nearby container ports are competing for traffic. Different factors have been identified as contributing positively to the attractiveness of a port, including the operational efficiency of its terminals, and its connections to hinterland. New critical questions arise from the increase of vessel sizes, the contention of service roads, the urge for massified, cleaner transport modes. Container terminal operations have received considerable attention in the literature in recent years. Most of the studies focus on one isolated problem that occurs in one terminal, e.g. berth planning, quay crane scheduling, storage space allocation, etc. Only a few studies consider globally the flow of containers through several terminals in a port. However, a better partitioning of the workload between terminals, and the use of specialized terminals or platforms to help massifying the flows, may significantly improve the enlarged port competitiveness. This presentation proposes a multi-periodic tactical model to handle vessels, barges, trains, trucks and their containers over several cooperating terminals. The problem is formulated as a mixed-integer linear program. We will present results on more than 2000 realistic instances with direct solving by a state of the art solver, with a relax-and-fix heuristic, and with a pre-assignment heuristic. Most of the 1600 instances with one fully-multimodal terminal or two specialized terminals were solved in less than 2 hours by the solver. Other instances required the use of heuristics.

Tuesday, 09:00-11:00

■ TA-01

Tuesday, 09:00-11:00 - HS 14

City Logistics 2

Stream: City Logistics
Chair: *Pamela Nolz*

1 - Modeling vehicle routing problems in urban areas
Nabil Absi, Hamza Ben Ticha, Dominique Feillet, Alain Quilliot

The vehicle routing problem (VRP) aims at planning a set of routes on a given road network, starting and ending at a central depot, for a fleet of vehicles that covers a set of customers' demands. Such problem is generally treated via the representation of the road network as a weighted complete graph. Arcs represent the shortest paths between pairs of vertices computed according to a single criterion generally travel distance. In real-life applications, one must take into account several objectives. Consequently, several attributes should be defined for one arc. Therefore, the representation with a complete graph could be insufficient to model the problem correctly. In this paper, we propose an alternative way of modeling vehicle routing problems in urban areas. It aims at extracting data from real road networks. In order to show the importance of modeling real road networks, we developed an efficient GRASP algorithm to solve the developed model. We show that our approach outperforms exact solution approaches for classical VRP models.

2 - Hybrid Heterogeneous Fleet Routing with City Center Restrictions
Gerhard Hiermann, Richard Hartl, Jakob Puchinger, Thibaut Vidal

An important area of research in the field of City Logistics studies the balance between the transportation requirements and the environmental impact on our growing cities. In this work, we investigate a concept to reduce local emissions of carbon dioxide by considering so-called city-center restrictions using a hybrid heterogeneous fleet of conventional, plug-in hybrid and pure electric vehicles.

We define such a city center as an area with limited number of entry and exit points where the use of conventional, fossil fuelled engines is restricted or prohibited. Such areas can be found in various medium and large cities, e.g., Malaga, Bologna, Milan and Paris. By restricting the use of fossil fuelled engines, the use of limited battery electric engines is encouraged, which reduces the local emissions of carbon dioxide considerably. However, this might lead to increased costs in form of detours or additional vehicles required due to additional, time consuming recharging operations. Furthermore, special care has to be taken in the operational evaluation of plug-in hybrid electric vehicles, where the driver can switch between the fossil fuelled and electric engine on route.

To study the impact of city centers, we conducted experiment on generated artificial benchmark instances based on well-known problem instances for related problems and instances based on real world street maps. We use labelling algorithms to make decisions on the path, the engine use and recharging station visits, embedded in our heuristic solver developed for handling hybrid heterogeneous fleets. First results will be presented at the conference.

3 - Synchronizing vans and cargo bikes in a city distribution network
Alexandra Anderluh, Vera Hemmelmayr, Rune Larsen, Pamela Nolz

Growing urbanization causes - amongst other things - a constantly increasing amount of freight transportation in cities, which is still mainly performed by conventional vans and trucks. These modes of transport produce a variety of problems like road congestion, nuisance and pollution. Nevertheless bringing goods to residents is also a necessity to maintain a good quality of life within the city. Sustainable concepts of city distribution networks are one way of mitigating difficulties of freight services. Our aim is to efficiently organize the distribution of goods in cities by consolidating the transport requirements of different stakeholders and using environmentally friendly transport modes in inner-city areas. Therefore, we develop a routing scheme with synchronization between cargo bikes and vans to fulfill this purpose. The

solution method we developed is based on heuristic and exact concepts, resulting in a fast approach which produces good feasible solutions. We use test instances, which are based on the Solomon instances, as well as a real-world Viennese test instance, where travel times are based on Floating Car Data from Viennese taxi drivers. Besides, to get more robust solutions in a real-world scenario we use a Monte Carlo Simulation approach to tackle stochastic service times at the customers by a critical path method. The results of our algorithm illustrate the costs caused by the need to synchronize vans and cargo bikes and can therefore give planners a decision support in using such a more sustainable kind of freight distribution in a city.

4 - An Efficient Heuristic Algorithm for the Alternative-Fuel Station Location Problem
Gábor Nagy, Trung Hieu Tran

The problem of alternative-fuel station location is a recent, but very applicable research topic within logistics. In essence, what makes the problem of determining locations of alternative-fuel stations different from those of petrol stations is the scarcity of current infrastructure. This topic is especially timely in the light of a recent European directive requiring Member States to provide a minimum coverage of such refuelling points. The flow-refuelling location model (FRLM) has its origins in the flow-capturing location model (FCLM). In turn, the FCLM is based on the observation that, unlike traditional location models, where facilities are to be sited near customer locations, in some cases it makes more sense to locate facilities near routes that customers already take. An important aspect of the FCLM is that any flow is captured by a single facility. The main difference of the FRLM from the FCLM is that a single facility may be unable to capture an entire flow, due to the issue of "limited range', namely, that some journeys cannot be undertaken with a single refuelling stop. (This model is applicable to vehicles powered by alternative fuels, as they normally cover relatively shorter distances on a full tank.) We propose an efficient heuristic for the FRLM that is based on the concept of solving sets of restricted subproblems. (In this respect it is somewhat similar to Kernel Search.) We also use a parallel computing strategy to reduce computation effort. We have carried out computational experiments on well-known benchmark datasets. Experimental results show that the proposed algorithm can obtain optimal solutions within a reasonable computation time and outperforms the other heuristics from the literature.

■ TA-02

Tuesday, 09:00-11:00 - HS 15

Bike Sharing

Stream: Bike Sharing
Chair: *Michal Tzur*

1 - Rebalancing Bike Sharing Systems
Jan Brinkmann, Marlin Wolf Ulmer, Dirk Christian Mattfeld

Many citys deal with a large volume of traffic. Drawbacks are traffic jams and environmental pollution, e.g., noise and carbon dioxide emmision. One approach to tackle these drawbacks is the use of bike sharing systems (BSS). In BSS, users rent and return bikes spontaneously at certain stations. Since mobility demands depend on the location and time, some stations tend to run out of bikes or may congest. To ensure that customers are able to use the service anytime, bikes have to be relocated. The relocations are realized by vehicles moving between stations to pickup and deliver bikes. In our article, we analize an exemplary problem that combines inventory and routing challenges. We regard a number of stations. Each station has a certain fill-level. To anticipate future demands, target fill-levels are provided by a tactical information system. Thus, we can identify overruns and shortages of bikes. The challenge is to balance the system with a fleet of capacity restricted vehicles. We propose a cluster-first-route-second approach. One main focus is to find suitable clusters. This can be done via variable neighborhood search by metaheuristics. For each cluster, an inventory routing algorithm generates a reallocation tour realizing target intervals. To evaluate our approache, we use real-world data from Vienna's BSS "CityBike". The target is to generate robust solutions. Computational studies point out, that realized target intervals are mainly able to handle stochastic user demands. In peak hours, target intervals cannot hold the stochastic demands.

2 - A Cluster-First Route-Second approach for Balancing Bicycle Sharing Systems
Christian Kloimüllner, Petrina Papazek, Bin Hu, Günther Raidl

Bicycle Sharing Systems (BSS) are gaining more and more popularity throughout the world as they have many positive effects on large cities and their population. However, as customers of a BSS can borrow a bike at any station and return it to any other station, rebalancing of bikes becomes necessary. In this work, we introduce a new problem definition which has not been considered in previous work. Instead of precisely calculating loading instructions for the vehicle fleet, we simplify the problem to only compute routes alternating between pickup and delivery stations, thus increasing scalability, and nevertheless having only a small loss of solution quality. In large and highly used BSS where much rebalancing is needed, it is beneficial to only pickup and deliver full vehicle loads because it is the most time-efficient way for the drivers to improve the system's balance. We approach this problem by a Cluster-First Route-Second (CF-RS) Strategy where, in the first step, CF-RS assigns stations to vehicles by a Mixed Integer Linear Programming (MIP) model, and in a second step, a Traveling Salesman Problem (TSP) is solved for each vehicle separately with the established and efficient Concorde TSP Solver. If the tour is too long according to the time budget (due to underestimated routing costs in the assignment problem), a Bender's Cut is added to the assignment MIP model and the whole approach is repeated. We show applicability, efficiency and solution quality of the proposed method by comparing it to other (meta-)heuristic approaches.

3 - Anticipating operational bike relocation in tactical service network design of bike sharing systems
Bruno Albert Neumann Saavedra, Patrick Vogel, Dirk Christian Mattfeld

Bike sharing enables sustainable means of shared mobility through automated rental stations in metropolitan areas. Spatio-temporal variation of bike rentals leads to imbalances in the distribution of bikes causing full or empty stations in the course of a day. Ensuring the reliable provision of bikes and bike racks is crucial for the viability of these systems. From a tactical planning perspective, service network design determines suitable fill levels of bikes at stations in the course of day providing reliability in service. On the operational planning level, the bike sharing operator relocates bikes in trucks from full to empty stations based on target fill levels. Neglecting relocation operations in service network design will lead to suboptimal fill level decisions. Thus, relocation operations have to be anticipated in service network design. Relocation operations are usually modeled as computationally challenging vehicle routing problems deciding on relocation services (pickup and return station, time period, number of relocated bikes) as well as their assignment to vehicles and sequencing in tours. We anticipate relocation in service network design by a dynamic transportation model in combination with a set partitioning model. The transportation model yields relocation services and the set partitioning model ensures the assignment of relocation services to compact service zones. Target fill levels can be directly implemented on the operational planning level. Service zones support operators of bike sharing systems in the planning and implementation of relocation operations. We present results for our approach based on the bike sharing system "Citybike Wien'.

4 - Detection and Collection of Broken Bicycles in Bike-Sharing Systems
Mor Kaspi, Tal Raviv, Michal Tzur

Bike sharing systems are nowadays implemented in more than 700 cities around the world. Most systems are equipped with information systems that allow users to verify in real-time the bicycle inventory levels in the systems' stations and plan their trips accordingly. Typically, a bicycle is used several times a day by different users. This increases the probability for damages, and indeed a small percentage of the fleet becomes broken every day. Currently, real-time information about the broken bicycles is not available for the operators or the users. As broken bicycles are not likely to be rented, it is unlikely that stations with broken bicycles will become empty. Therefore, the system may keep signaling to the users and the operators that there are available bicycles in such stations even though such bicycles are unusable. These occurrences may cause great inconvenience to the users due to the false information. In this study we present a probabilistic model that can be used to detect broken bicycles and report them in real-time. In addition, we provide a method to measure the effect of broken bicycles on the service level of the system. Furthermore, the output of the probabilistic model is used as an input for an optimization model that integrates the collection of broken bicycles with

repositioning activities. Incorporating maintenance aspects is another step towards modeling and solving the real operational problem bike sharing operators are facing.

■ TA-03
Tuesday, 09:00-11:00 - HS 16

Multi Objective Routing

Stream: Multi-Objective Routing
Chair: *Kris Braekers*

1 - Solving multi-objective vehicle routing problem by using interactive approach
Raza Khan, Julia Handl, Jian-Bo Yang

In this research, we deal with the vehicle routing problem with an aim of finding the preferred trade-off solution when multiple and conflicting objectives are considered in time-varying congestion road network in an urban delivery context. Contrary to the common a-priori and a posteriori approaches, we use an interactive method that takes into account the preferences of the decision maker at each iteration step. A heuristic algorithm based on dynamic programming and genetic algorithm is used to rank the population and to guide the search in the preferred direction of decision maker. The model is applied to synthetic demand data with actual road and congestion information from UK. The results obtained through the interactive method are compared with those obtained for when different single objectives are optimised.

2 - A prioritized bicriteria heuristic for multi-vehicle collection for processing problem
Eda Yücel, Sibel Salman, E. Lerzan Ormeci, Esma Gel

In this research, we study the multiple-vehicle collection for processing problem. The research is motivated by our experience at a U.S.-based clinical laboratory. The specimens that accumulate at customer sites over time should be transferred by a number of vehicles to a facility for subsequent processing on equipment with limited capacity. The problem is to construct and schedule a series of tours of multiple vehicles in order to collect accumulated specimens from the sites throughout the day. The first level objective is to maximize the daily processed amount, while minimization of the daily transportation costs is of secondary priority. A two-phase prioritized bicriteria heuristic is proposed to address the problem. In the first phase, the set of sites is partitioned into disjoint clusters, where each cluster is assigned to a single vehicle. In the second phase, a tabu search-based algorithm is used to determine the daily schedule of each vehicle. To evaluate the performance of this approach, we develop an MIP-based solution approach. The effectiveness of the proposed solution approach is analyzed using realistic problem instances.

3 - A Hybrid Evolutionary Algorithm for the Biobjective Capacitated m-Ring Star Problem
Herminia I. Calvete, Carmen Galé, Jose A. Iranzo

The bi-objective capacitated m-ring star problem consists of finding a set of m simple cycles through a subset of nodes of a network. The set of nodes consists of a central depot, a set of customers and a set of Steiner points. The customers not in any ring are directly connected to nodes in the rings. The rings must be node-disjoint except for the depot and the total number of customers in a ring or connected to a ring is limited by its capacity. The two objective functions refer to the cost due to the links of the rings and the cost of allocating customers to nodes in the ring. In this paper, we propose a metaheuristics for approaching the Pareto front which embeds a local search procedure inside an evolutionary algorithm. The algorithm is tested on benchmark instances providing better results than previous algorithms proposed in the literature.

4 - Solving a bi-objective dial-a-ride problem using multi-directional local search and an exact scheduling procedure
Yves Molenbruch, Kris Braekers, An Caris

A dial-a-ride system is an application of demand-responsive, collective people transportation. Each user requests a trip between an origin and a destination of choice, to which a number of service level requirements are linked. The service provider attempts to develop efficient routing schedules, respecting these service level requirements and the technical constraints of a pickup and delivery problem. The balancing

of human and economic perspectives involved in solving such a dial-a-ride problem explains why these systems are particularly useful for organizing quality-oriented, but efficient transportation for users having special needs, such as door-to-door transportation for elderly and disabled. Since demand for dial-a-ride systems is increasing, service providers need efficient planning algorithms to safeguard quality and cost efficiency.

Single-objective methods usually minimize operational costs while ensuring a minimum quality level imposed by the service level requirements. This solution technique emphasizes the fundamental nature of the problem by solving a bi-objective dial-a-ride problem with real-life characteristics. Total user ride time, being the total time users spend aboard the vehicles, is explicitly minimized as an additional, quality-oriented objective without making a priori choices regarding the importance of both objectives. To this end, a multi-directional local search (MDLS) metaheuristic is developed, in which a variable neighborhood search (VNS) principle is embedded to perform local search. An exact scheduling procedure is integrated into the metaheuristic framework in order to produce schedules which minimize total user ride time. Although a bi-objective case is considered here, the principle of MDLS allows any number of objectives.

■ TA-04

Tuesday, 09:00-11:00 - HS 17

Assignment Problems

Stream: Assignment Problems
Chair: *Stein W. Wallace*

1 - Dynamic Facility Design Considering Zones
Sadan Kulturel-Konak

The Dynamic Facility Layout Problem (DFLP) considers designing a facility in a multi-period planning horizon. The DFLP in the continuous plane is a very challenging nonlinear optimization problem. In this study, a zone-based block layout is under consideration to design manufacturing and logistics facilities considering material handling infrastructure. A hybrid approach is proposed to solve the zone-based DFLP on the continuous plane with unequal area departments. Therefore, mathematical optimization modeling and zone-based formulation of the single layout problem is applied in the context of the DFLP. Promising numerical results are presented for a comprehensive set of test problems from the literature.

2 - An alternating cycle heuristic for the resource-constrained assignment problem
Markus Reuther

The resource constrained assignment problem (RCAP) is to find a minimal cost cycle partition in a directed graph such that a resource constraint is fulfilled. The RCAP has its roots in an application that deals with the covering of a railway timetable by rolling stock vehicles. Here, the resource constraint corresponds to maintenance constraints for rail vehicles. Moreover, the RCAP generalizes several variants of vehicle routing problems. We contribute a local search algorithm for this problem that is derived from an exact algorithm which is similar to the Hungarian method for the standard assignment problem. Our algorithm can be summarized as a k-OPT heuristic, exchanging k arcs of an alternating cycle of the incumbent solution in each improvement step. The alternating cycles are found by dual arguments from linear programming. We present computational results for instances from our railway application at Deutsche Bahn Fernverkehr AG as well as for instances of the vehicle routing problem from the literature, e.g., the capacitated vehicle routing problem and the traveling salesman problem.

3 - A matheuristic for stochastic gate assignment in LTL terminals
Lars Eufinger, Uwe Clausen

Freight forwarding companies in the less-than-truckload (LTL) industry are under strong competitive pressure. Due to this pressure companies are trying to gain a competitive advantage by systematically optimizing the processes and the implementation of logistics innovations. We want to investigate LTL terminals which are the hubs of the LTL transportation networks and operate as distribution centers with the collection and distribution function of goods, e.g. cross docking.

The task of a LTL terminal is the accurate and in time handling of shipments between vehicles on short-distance traffic and transport vehicles on long-distance traffic. The performance of a LTL terminal is largely determined by the proper use of the gates. A gate assignment plan should minimize the waiting times of the trucks while having short transportation distances inside the terminal. However, many uncertain factors influence the planning. Fluctuations can occur in both, the arrival times of vehicles as well as changes in the transported goods. Thus it is reasonable to use stochastic optimization to create a gate assignment plan which can handle the occurring uncertainties. We present our stochastic optimization model for the assignment of the trucks to the gates, taking into account the processes inside the terminal, e.g. the movements of the goods from gate to gate. In addition to this, we present our matheuristic solution method of the optimization model, which is based on a scenario decomposition approach using 2-stage-stochastic optimization and first computational results.

4 - Stochastic facility layout design: distance measures and plant shapes
Stein W. Wallace, Yifei Zhao

This talk analyzes how facility layout design is affected by such as the shape of the plant, the number and placement of doors for dispatching and finishing materials, the choice of distance measure (determined by choice of technology), and the cost of picking and dropping materials. We perform the analysis within the framework of Quadratic Assignment based models, and we focus on the case of random demand and capacitated machines.

■ TA-05

Tuesday, 09:00-11:00 - Sky Lounge

Rich VRPs 2

Stream: Rich VRPs
Chair: *Javier Faulin*

1 - A decomposition approach to the prisoner transportation problem
Jan Christiaens

The prisoner transportation problem (PTP) is a generalization of the pickup and delivery problem with time windows (PDPTW). The PTP involves assigning prisoner transportation orders to a heterogeneous fleet of vehicles. Safety requirements related to individual prisoners should be satisfied by selecting appropriate vehicle types. A particularly interesting constraint determines conflicts between sets of prisoners, when at the same time in a vehicle or in a vehicle compartment. The real world objective is to minimize the operational costs induced by the required staff, number of vehicles, traveling distance, etc. A heuristic decomposition approach consists of a VRP and a graph coloring heuristic. The heuristics strongly rely on problem-specific data structures. Experiments have been conducted on real world data and the results have been compared with previously constructed schedules at a prisoner transportation company. The heuristically obtained schedules outperform current practice, both in terms of costs and computation time.

2 - A Greedy Randomized Adaptive Search for the Vehicle Routing Problem with Clustered Backhauls
Massimo Di Francesco, Gavina Baralla, Gianfranco Fadda, Simona Mancini, Simone Zanda, Paola Zuddas

The Vehicle Routing Problem with Clustered Backhauls (VRPB) is an extension of the classical VRP in which two sets of customers are involved: Linehauls, to whom goods have to be delivered and Backhauls, whose goods have to be picked up and transported back to the depot. In addition, in each route all linehaul customers must be visited before any goods can be picked up from backhaul ones, to avoid rearranging the load on the vehicle. The objective is to provide minimum cost vehicle routes such that each customer is served and each vehicle load does not exceed its capacity. To solve this problem we propose a Greedy Randomized Adaptive Search (GRASP), a multistart metaheuristic which consists of a constructive procedure, based on a greedy randomized algorithm, combined with a local search. In the constructive phase, the last linehaul and the first backhaul are determined and, next, two open routes from these nodes to the depot are constructed, so that the resulting routes are feasible for the VRPCB. At each step of the constructive phase, the next node to be included in the route is

randomly chosen within a Restricted Candidates List (RCL) obtained basing on the distance from the previous node in the route, the distance from the depot and the residual capacity of the vehicle. The local search consists into a node-relocation procedure with first improvement. We compare results obtained on a large set of benchmark instances with the best-known solutions present in literature.

3 - Solving the Fleet Size and Mix Vehicle Routing Problem with Backhauls using a Multi-Round Biased Randomized Heuristic Method
Javier Belloso, Angel A. Juan, Javier Faulin, Adrian Serrano

We consider the Fleet Size and Mix Vehicle Routing Problem with Backhauls (FSMVRPB) as introduced in Salhi et. al (2013). In the present variant, the routes start and finish in a central depot, the customers can be either linehaul or backhaul and we have a heterogeneous unlimited fleet of vehicles. Therefore, there are no constraints in the types and number of vehicles to be used. The proposed algorithm uses a successive approximations logic that is implemented through a multi-round structure. A framework to guide the process of finding the fleet composition by solving iteratively a number of homogenous VRPB problems that coincides with the number of vehicle types is designed. Three randomised criteria are used. The first one to select the order in which vehicles are used, and the second one to order the savings list used to decide who the next customer to be visited is. Once the type of vehicle is selected, the algorithm solves the homogeneous problem with the not-yet-visited customers considering an unlimited number of vehicles. The number of routes of this solution that will be part of final solution depends on the third random criteria. Benchmark instances for the FSMVRPB have been selected in order to assess the efficiency of our approach, and initial results show that our approach is able to provide promising solutions.

References

Salhi. S.. Wassan. N.. Hajarat. M.. 2013. The fleet size and mix vehicle routing problem with Backhauls: Formulation and Set Partitioning-based Heuristic. Transportation Research Part E: Logistics and Transportation Review 56. 22—35.

4 - Visual Interactive Heuristic Solution Methods for Multi Depot Vehicle Routing Problem with Heterogeneous Vehicle Fleet
Fatih Kocatürk, G.Yazgı Tütüncü

Vehicle Routing Problems (VRP) consist of a large number of customers or stations, each requiring a specified weight of goods to be delivered by a fleet of vehicles. In the last 50 years, vehicle routing has appeared as one of the major areas of both research and practice in the field of management science and operations research. In real life, vehicle routing problems include additional requirements and difficulties beyond the basic VRP. In our study, we consider Multi Depot VRP with Heterogeneous Vehicle Fleet (MDVRPHVF) and MDVRPHVF and Backhauls (MDVRPHVFB) which are faced usually in real life and taken into account by many supply chain companies. We will develop a visual interactive DSS, which is applicable in real life and able to solve these problems by heuristic methods, for the considered problems. There is only one study of Salhi et al., (2013) about MDVRPHVF and as far as we are aware until now there is no study about MDVRPHVFB in the literature. These problems are most common VRP extensions in real life. Therefore, the solution of these problems will act so effectively in decreasing the total cost of the firms which have supply and distribution problems. Existing algorithms for VRP in the literature generally cannot be applied to real life problems appropriately and it is very difficult for non-specialist people to find a solution. However, the users (the decision makers) can easily interact with the solution process dynamically without help of a specialist by using the developed DSS. The users can change the best solution found by the DSS with respect to their demands and experience and they can see the resulting cost differences immediately. To the best of our knowledge, there is no such a DSS for the considered problems in the literature.

Tuesday, 11:30-13:00

■ TB-01
Tuesday, 11:30-13:00 - HS 14

VRPs with Profits

Stream: VRPs with Profits
Chair: *Gilbert Laporte*

1 - A branch-and-price algorithm for the Team Orienteering Arc Routing Problem
Jorge Riera-Ledesma, Juan José Salazar González

We consider in this work the Team Orienteering Arc Routing Problem. It is a variation of the well known Team Orienteering Problem where the set of customers is given by a subset of arcs in a directed graph. In this problem a set of vehicles has to mandatorily visit a subset of the customers. There is also a profit associated with the remaining ones, thus, in some circumstances is convenient visiting some of these customers. The time consumed by each vehicle along the route is bounded. We propose a set partitioning formulation for this problem, leading to a column generation algorithm. The performance of this algorithm has been studied on a wide family of benchmark test instances . We have observed that, as the number of vehicles grows, our proposal shows a better performance than other previous exact algorithms in the literature.

2 - A Selector Operator-Based Adaptive Large Neighbourhood Search for the Orienteering Problem
Leticia Vargas, Nicolas Jozefowiez, Sandra Ulrich Ngueveu

This study addresses a difficult combinatorial optimisation problem called the Orienteering Problem or Selective Traveling Salesman Problem. It borrows its name from a sport game named orienteering in which competitors select a cycle from a specified start, and collect a prize by visiting, within a given time frame, as many intermediate points as possible. Then, in the Orienteering Problem, a set of locations is given, each with an associated non-negative profit, and the travel between locations involves a known cost. The problem calls to select a set of points to visit, so that the total profit collected is maximised subject to a constraint on the total travel cost allowed. A number of applications in logistics, tourism, vehicle routing, production scheduling and other fields have been modelled as orienteering problems. The problem has been shown to be NP-hard, and accordingly, several heuristics have been proposed in the literature. We present a solution procedure centred on a Selector operator which is dynamic programming based, but at the same time makes use of a combination of techniques that allow to avoid the combinatorial explosion of states. This operator is embedded in an adaptive large neighbourhood search, a local search framework composed of several competing destroy and repair sub-heuristics which are chosen during the search with a frequency corresponding to their historic performance. The method is highly competitive as shown by the quality of results obtained through computational experiments conducted on standard benchmark instances, and evaluated against the output of a state-of-the-art heuristic and exact algorithm.

3 - A Priori Route Evaluation for the Lateral Transhipment Problem with Piecewise Linear Profits
Martin Romauch, Richard Hartl, Thibaut Vidal

We propose exact solution approaches for evaluating a priori route for the lateral transhipment problem. For a prespecified ordering of customers, an optimal inventory redistribution plan is sought, considering travel costs, profits (dependent on the local inventory levels) and holding costs. Constraints on trip duration and vehicle capacities are also imposed. This problem, with fixed routes, arises when enumerating solutions (or solution subspaces) of a vehicle routing problem for lateral transhipments with piecewise linear profits, during heuristic resolution. The same problem is also encountered when dealing with lot sizing applications, in the presence of setup costs and equipment requalifications. To address this problem, we introduce a pure dynamic programming approach and a branch-and-bound framework that combines dynamic programming with Lagrangian relaxation. Expensive experiments are conducted to determine the most suitable resolution approach for different instances, depending on their size, vehicle capacities and duration constraint. The performance is compared to Gurobi as one representative of a commercial state of the art optimization solver. The proposed Branch-and-bound and Lagrangian relaxation approach, in particular, solves problems of up to 50 delivery

locations in less than one minute on a modern computer, outperforming Gurobi for most benchmark instances.

■ TB-02

Tuesday, 11:30-13:00 - HS 15

Collaborative Vehicle Routing 2

Stream: Collaborative Vehicle Routing
Chair: *Christof Defryn*

1 - Collaborative distribution center location with outbound transportation by common carriers
Begum Giray, Gultekin Kuyzu

We study a facility location problem motivated by horizontal collaboration in logistics and supply chain management. We consider a group of suppliers each of which aims to establish one or more distribution centers, to be able to quickly and economically respond to customers orders from a given area. The customer orders are not in very large quantities, so the suppliers utilize the services of less-than-truckload (LTL) common carriers to deliver their products to the customers. LTL carriers typically charge less per unit weight as the shipment weight increases, resulting in a piecewise linear cost function. A customer location typically receives products from multiple suppliers. The suppliers are interested in collaborating with each other to reduce the cost of meeting customer demand. The collaboration model they consider entails establishing joint distribution centers to alleviate the burden of fixed facility costs, and consolidating outbound freight from each joint distribution center to reduce outbound transportation costs. In order to establish a successful collaboration, the suppliers must determine: (i) the members of the collaboration, (ii) the operational structure of the collaborative solution, and (iii) the method of sharing the costs of the collaboration.

In this paper, we develop mathematical programming models which aim to select the optimal combination of partners, facility locations and customer assignments, and at the same time incorporate cost allocation decisions for the stability of the collaboration. Based on our review of the literature, this is one of the first studies covering all three of these important aspects. The resulting models are selective facility location models with piecewise-linear transportation costs, which is not commonly used in the literature. We evaluate the performance of our models on test instances.

2 - Collaborative truckload transportation procurement with multiple coalitions
Soheyl Zehtabiyan, Gultekin Kuyzu

Collaborative truckload transportation procurement is a form of horizontal collaboration in the supply chain. In this form of collaboration, a group of shippers purchasing the services of carriers come together and jointly negotiate with carriers for better rates. Selecting the participants, deciding who should participate with whom, calculating the lowest cost operational solution, and allocating the system-wide cost to the participants stand out as important problems. Collaborating shippers try to identify tours which consist of regularly scheduled shipments with minimal empty truck movements. They must then allocate the total cost of the collaborative solution to the participating firms and individual lanes such that the collaborative solution remains attractive to the participants.

In the literature, solving the optimization problem minimizing the total cost and allocating the calculated minimum cost are treated as two successive but distinct phases. The cost minimizing optimization problem is solved with well-known operations research methods while cooperative game theory concepts are used for cost allocation. The minimum cost solution may render finding an acceptable cost allocation impossible. In addition, similar works in the literature assume that the collaborating firms will form a single grand coalition. As the collaboration grows in size, a single grand coalition may become impractical.

In this study, we develop algorithms to design coalition structures which consist of multiple disjoint stable coalitions. Each coalition must have a minimum cost collaborative solution with an acceptable cost allocation. Due to the complexity of the task hand, we devise heuristics to find good quality solutions to this problem. We test the effectiveness of our algorithms on randomly generated test instances.

3 - Combinatorial Auctions in Freight Logistics: state-of-the-art
Afroditi Anagnostopoulou, Eleftherios Sdoukopoulos, Maria Boile, Sotirios Theofanis, Dimitris Margaritis

New information technologies and co-operation mechanisms can create many opportunities for enhancing the freight transport system by addressing any existing inefficiencies thus improving the performance and viability of the transport industry. Electronic marketplaces have emerged as a result of the advances in information technology, and B2B and B2C hubs have been developed to facilitate product and information exchange and support the negotiation, contracting and settlement. In particular, auction systems can possibly improve the operation of the freight transport system, and to this end, their potential has been largely investigated through several studies focusing mainly on the development of their architecture and related optimization, auctioning and load matching algorithms.

This paper discusses the latest research trends and developments in the field of combinatorial auction optimization in freight logistics and some issues that have not received attention so far are highlighted. Hence, the scientific background of the modern freight auction systems is presented and the benefits offered to shippers and/or carriers are discussed. Due to their high complexity, significant developments have been made towards the design of heuristic and metaheuristic methods. For this reason, the main effort of this paper is not only to provide an overview of the literature presenting the interest of the research community, but also to identify the components of a successful algorithm that could be implemented in a freight auction platform in practice. A particular emphasis is put on the fact that the problem studied both from the shippers and the carriers' aspect, analyzing the proposed problem formulations and the corresponding mathematical models as well as the solution approaches developed to deal with.

■ TB-03

Tuesday, 11:30-13:00 - HS 16

Exact Solution of VRPs 2

Stream: Exact Solution of VRPs
Chair: *Luís Gouveia*

1 - New Exact Solution Approaches for the Split Delivery Vehicle Routing Problem
Gizem Ozbaygin, Oya Ekin-Karasan, Hande Yaman

In this study, we propose exact solution methods for the Split Delivery Vehicle Routing Problem (SDVRP). We first give a new vehicle-indexed flow formulation for the problem, and then, a relaxation obtained by aggregating the vehicle-indexed variables over all vehicles. This relaxation may have optimal solutions where several vehicles exchange loads at some customers. We cut-off such solutions either by extending the formulation locally with vehicle-indexed variables or by node splitting. We compare these approaches using instances from the literature and new randomly generated instances. Additionally, we introduce two new extensions of the SDVRP by restricting the number of splits and by relaxing the depot return requirement, and modify our algorithms to handle these extensions.

2 - Comparison of Three Classes of MIP Formulations for the Generic CVRP
Mir Ehsan Hesam Sadati, Deniz Aksen, Temel Öncan

The single depot capacitated vehicle routing problem (CVRP or simply VRP) is a generic name given to a whole class of problems involving the visiting of "customers" by "vehicles" and is one of the most studied combinatorial optimization problems in the OR literature. The VRP appears very frequently in practical situations related to the physical delivery of goods, and its extensions have countless real-life applications in a diverse array of industries ranging from collection and distribution to public transportation to humanitarian logistics. In this research, we look into three fundamental classes and categorically developed subclasses of mixed integer programming (MIP) formulations for the VRP. These three fundamental formulations are: 1. Lifted Miller-Tucker-Zemlin subtour elimination constraints and load variables (designated as MTZ). 2. Single commodity flow formulation of

Gavish and Graves with continuous flow variables and flow conservation constraints (designated as GG). 3. Two alternative VRP models with precedence relations: i) Precedence constraints using three-index routing variables and two-index node-to-route assignment variables (designated as PC3), ii) A model similar to PC3, but involving two-index routing variables instead of three-index (designated as PC2). We test the efficiency (solution time impact) and effectiveness (impact on upper and lower bounds) of several well-known valid inequalities and novel logical and coupling constraints adapted to the VRP. We also report the result of partial LP relaxations of these three fundamental models.

3 - Improved Integer Linear Programming Formulations for the Job Sequencing and Tool Switching Problem
Luís Gouveia, Daniele Catanzaro, Martine Labbé

In this article we investigate the job Sequencing and tool Switching Problem (SSP), a NP-hard combinatorial optimization problem arising from computer and manufacturing systems. Starting from the results described in Tang and Denardo (1987), Crama et al. (1994) and Laporte et al. (2004), we develop new integer linear programming formulations for the problem that are provably better than the alternative ones currently described in the literature. Computational experiments show that the lower bound obtained by the linear relaxation of the considered formulations improve, on average, upon those currently described in the literature and suggest, at the same time, new directions for the development of future exact solution approaches.

■ TB-04
Tuesday, 11:30-13:00 - HS 17

Green VRPs 2

Stream: Green VRPs
Chair: *Bülent Çatay*

1 - An Iterated Beam Search algorithm for the Green Vehicle Problem in Service Fleets
Mesut Yavuz

This talk presents a novel Iterated Beam Search (IBS) solution to the Green Vehicle Routing Problem (GVRP) in Service Fleets. The GVRP consists in minimizing the total distance traveled by a homogeneous fleet of green, alternative-fuel vehicles. Green vehicles are preferable over traditional gasoline or diesel vehicles with their lower carbon emissions and/or variable (per-distance) fuel costs. However, their limited driving range, limited refueling infrastructure, and — in the case of electric vehicles — lengthy refueling times rise unique constraints. Service fleets are more suitable for green vehicles due to the significant (such as an hour) service times that operators spend at customer sites. In addition, some customer sites may already have refueling infrastructure for a green vehicle, and, hence, visits to those customers may increase its remaining driving range. In order to solve this new VRP variant, the talks present an IBS heuristic, which generalizes the beam search heuristic, a tree-search algorithm which itself generalizes the greedy method. The success of IBS relies on lower- and upper-bounding mechanisms incorporated into the algorithm. In this talk, two alternative mathematical formulations — one based on vehicle flows and the other on set partitioning — of the problem are built and a lower bounding mechanism is developed for each. For fast upper bounding, two heuristics — namely savings and insertion — are adopted to the problem. A computational experiment is designed to compare the four resulting IBS heuristics over a wide span of scenarios.

2 - An emission vehicle routing problem with split deliveries
Benedikt Vornhusen, Herbert Kopfer

In recent years, environmental protection has received significant attention and hence, the impact of freight transportation to environmental pollution is becoming crucial. On the one hand, road freight transportation is essential for economic success, and on the other hand, it is one of the main polluter. In order to achieve political as well as social purposes greenhouse gas emissions caused by road haulage have to be reduced. Therefore, new planning methods need to be developed. The amount of combusted diesel on a route depends to a large extend on the curb weight and the actual payload of the used vehicles. Thus, using an adequate mixed fleet and building CO_2-minimized tours for the vehicles of this mixed fleet opens up options for reducing CO_2 emissions caused by transportation. A further possibility to reduce emissions investigated in our research is to allow split delivery within the mixed vehicle routing problem. A mixed-integer mathematical linear program has been formulated and implemented. The required fuel depending on the vehicle weight is computed with the online tool EcoTransIT, which estimates the emissions for different vehicle classes on a given tour. To demonstrate the potential of split deliveries to the reduction of emissions, we show results of our model on generated instances.

3 - Time-Dependent Emission Vehicle Routing Problem
U.Mahir Yildirim, Bülent Çatay

We address the Time-Dependent Emission Vehicle Routing Problem (TDEVRP) as a variant of Time-Dependent VRP where the objective is to minimize the greenhouse gas emissions. In TDEVRP, the vehicle routes and the corresponding customer-to-customer journey paths are determined simultaneously using the least emission generating (greenest) paths from one customer to another for different departure times throughout the day. To solve this problem we adapt the MathAnt of Yıldırım and Çatay (2014), a matheuristic approach that was proposed to solve VRP with Time-Windows. MathAnt uses an ant algorithm to construct a pool of good solutions and periodically enhances it by solving the mathematical programming formulation of the problem. We first test the performance of the algorithm using both time-dependent and -independent (static) VRP variants. Our experiments show promising results, including improvements of some best-known solutions reported in the literature. Next, we solve TDEVRP and compare the routes to those obtained by solving the static problem on the basis of both distance and emissions. We provide insights on how time-varying speeds and the use of greenest paths between customer pairs might affect the route plans and how substantial reductions in emissions can be achieved with different route and journey path decisions.

■ TB-05
Tuesday, 11:30-13:00 - Sky Lounge

Waste Collection Problems

Stream: Waste Collection Problems
Chair: *Daniele Vigo*

1 - Routing and Demand Estimation in a Generalized Waste Collection VRP
Iliya Markov, Sacha Varone, Michel Bierlaire

We propose a new recyclable waste collection problem, which extends the vehicle routing problem with intermediate facilities, integrating a heterogeneous fixed fleet and a flexible assignment of start and end depot. Several additional side constraints reflecting the applied nature of the problem are also considered. The problem is modeled as a MILP and enhanced with several valid inequalities. For large realistic instances, we develop a local search heuristic, which achieves optimality on small random instances, exhibits competitive performance in comparison to state-of-the-art solution methods for special cases of our problem, and leads to important savings in the state of practice. The operational relevance of the routing algorithm depends on the good estimation of the container waste volumes at the time of executing the tours, which are often planned several days ahead. To this end, we develop a waste generation model from spatially disaggregated historical data on daily container volumes, population density, geography, spatial container interaction measures, weather, holidays, and container specific effects. Derived from a dynamic spatial panel regression, the model is able to forecast individual container volumes, successfully capturing the strong weekly seasonality pattern in waste generation. This research is the first step in a holistic approach to waste collection management, combining demand and supply in a single framework.

2 - Design of a household waste collection system for insular zones
Pablo Miranda, Carola Blazquez

This research addresses the problem of designing a household waste collection system for serving rural insular areas using a barge for waste transportation. A novel mixed integer programming model is proposed that simultaneously integrates decisions of waste collection sites selection within the islands to be served, visit schedule for each selected collection site, and multi-period vehicle routing and scheduling. In addition, the proposed model is employed to evaluate two different operating strategies for collecting the waste from the islands to be served. One strategy is based on using the barge for transporting full

and empty bins, and a second strategy consists of using a compacting equipment to transport only the waste on board the barge. Valid inequalities are incorporated in the formulation in order to make feasible to solve the problem. An application to a real-world instance consisting of small rural islands located in the south of Chile shows the effectiveness and complexity of the model, along with the advantages of using a waste compactor instead of transporting the waste using bins onboard a barge.

3 - An algorithm for solving selective waste collection problem

Ana Dolores López Sánchez, Rafael Caballero, Alfredo G. Hernandez-Diaz, Julian Molina, Daniele Vigo

Waste collection problem is an interesting class of rich vehicle routing problems that is of high practical relevance. We present a waste collection problem in Seville having into account each fraction of waste. This specific problem is modeled as a Period Vehicle Routing Problem with Service Choice (PVRP-SC) that is a variation of the classic vehicle routing problem (VRP) in which routes are constructed for a period of time and where the service frequency is a decision model.

The objective of our real-world problem is first to minimize the set of vehicles to collect each fraction of waste and then to find a set of tours for each vehicle for each day over a period that minimizes the total travel cost time while satisfying constraints (vehicle capacity and visit frequency minima).

The algorithm proposed to solve the PVRP-SC will be presented and some preliminary results will be shown.

Tuesday, 14:30-15:30

■ TC-01

Tuesday, 14:30-15:30 - HS 14

Plenary: Bektas

Stream: VEROLOG PLENARY
Chair: *Jakob Puchinger*

1 - The elegant waltz of a vehicle fleet: reducing pollution and cost in routing

Tolga Bektas

Road freight transportation is one of the contributors to greenhouse gas emissions (GHG), the amount of which is directly proportional to the fuel consumed by vehicles. In this talk, I will discuss ways in which emissions and fuel consumption can be accounted for and reduced in vehicle routing. In particular, I will introduce pollution-routing problems, present the recent algorithmic advances on such problems, and show results that shed light on the interactions of various parameters such as the vehicle weight, load, speed and total cost.

Wednesday, 09:00-10:30

■ WA-01

Wednesday, 09:00-10:30 - HS 14

Packing & Routing 2

Stream: Packing & Routing
Chair: *Marilène Cherkesly*

1 - Branch-Price-and-Cut Algorithms for the Pickup and Delivery Problem with Time Windows and Multiple Stacks

Marilène Cherkesly, Guy Desaulniers, Stefan Irnich, Gilbert Laporte

We model and solve the pickup and delivery problem with time windows and multiple stacks. Each stack is rear-loaded and is operated in a last-in-first-out (LIFO) fashion, meaning that when an item is picked up, it is positioned at the rear of a stack. An item can only be delivered if it is at the rear of a stack. This problem arises in the transportation of heavy or dangerous material where unnecessary handling should be avoided, such as in the transportation of cars between car dealers and the transportation of livestocks from farms to slaughterhouses. To solve this problem, we propose two different branch-price-and-cut algorithms. The first solves the shortest path problem with the LIFO multiple stacks policy, while the second incorporates this policy partly in the shortest path problem and adds additional inequalities to the master problem when infeasible LIFO multiple stacks routes are encountered. Computational results will be presented on instances comprising up to 75 requests. Preliminary computational results reveal the advantage of incorporating the LIFO multiple stacks policy in the shortest path problem.

2 - Iterated local search for the CVRP with sequence-based pallet loading and axle weight restrictions

Hanne Pollaris, Kris Braekers, An Caris, Gerrit K. Janssens, Sabine Limbourg

An Iterated Local Search method (ILS) for the CVRP with sequence-based pallet loading and axle weight restrictions is presented. The problem considers the distribution of europallets to various locations and takes sequence-based loading as well as axle weight limits into account. Sequence-based loading ensures that no consignment is placed in such a way that it blocks the removal of items to be delivered earlier on the route. Pallets are placed in two horizontal rows inside the vehicle and cannot be vertically stacked. According to a survey among Belgian logistics service providers, axle weight limits impose a challenge for transportation companies since they face high fines when violating these limits. A metaheuristic as well as a matheuristic are developed for two variants of the problem. In the first problem type, pallets are packed dense, which means that there may be no gap between two consecutive pallets inside a vehicle. Dense packing makes it easier for the driver to secure the cargo than when pallets are spread over the vehicle. In the second problem type, gaps between pallets of consecutive customers are allowed. A single customer sequence therefore may result in different possible packing schemes. In this case, the feasibility check in terms of axle weight limits is solved exactly with Cplex. The resulting solution method is a matheuristic since the routing problem is solved heuristically while the loading feasibility check is computed exactly. The structure of the ILS as well as results will be presented.

3 - The Value of Integrating Loading and Routing

Gianfranco Guastaroba, Jean-François Côté, M. Grazia Speranza

In the classical Capacitated Vehicle Routing Problem (CVRP) the demand of each customer is expressed by a single value, usually representing the total weight of the items to be transported. Nevertheless, in many real-world applications these items are characterized not only by a weight but also by a shape. In these situations, a solution that is feasible for the CVRP may prove to be infeasible in practice as it is impossible to determine a loading pattern to allocate the items within the loading area of the vehicles. This observation motivates the study of routing problems integrated with loading constraints.

We consider the CVRP with Two-dimensional Loading constraints (2L-CVRP), a variant of the CVRP where rectangular items have to be transported and loading constraints have to be satisfied. These loading issues are related to multi-dimensional packing problems. The prevailing attitude among researchers has been, until recently, to tackle each problem independently, at the expense of the global optimization. We aim at motivating the need for an integrated (and more difficult to solve) formulation for the 2L-CVRP, quantifying the magnitude of the benefits that can be achieved addressing directly the integrated problem instead of tackling each problem independently. We solve the 2L-CVRP using an exact algorithm. We compare the solutions of the integrated problem with those obtained applying two non integrated approaches where the CVRP and the loading problem are sequentially taken into consideration. We show that large benefits can be achieved.

■ WA-02

Wednesday, 09:00-10:30 - HS 15

Pickup & Delivery 2

Stream: Pickup & Delivery
Chair: *Thibaut Vidal*

1 - An ALNS for the one-to-one pickup and delivery TSP with handling costs

Marjolein Veenstra, Kees Jan Roodbergen

In this paper, we model and solve the one-to-one pickup and delivery traveling salesman problem with handling costs (PDTSPH). We consider a rear-loaded vehicle with a single compartment operated in a last-in-first-out (LIFO) fashion. The LIFO stack implies that when the vehicle arrives at a pickup location, the item is positioned on top of the stack. An item can be delivered without handling when it is on top of the stack, otherwise handling is needed and is penalized. The item sequence remains the same after the handling operations. The objective is to minimize a weighted sum of the travel distance and penalty costs. This problem is a generalization of the pickup and delivery traveling salesman problem (PDTSP) and the PDTSP with LIFO (PDT-SPL). Setting the penalty of the handling operations sufficiently small, the problem reduces to the PDTSP, whereas a sufficiently large penalty reduces the problem to the PDTSPL. We propose an adaptive large neighborhood search metaheuristic to solve the PDTSPH and provide computational results on known instances for the PDTSPL. We show the impact of the value of the penalty for the handling operations in different settings. We indicate the need to include handling operations in the generation of routes, and show that relaxing the LIFO policy can be valuable.

2 - The Pickup and Delivery Problem with Split Loads: A Random Variable Neighborhood Descent Heuristic

Matheus Nohra Haddad, Thibaut Vidal, Richard Hartl, Luiz Satoru Ochi, Marcone Jamilson Freitas Souza

The Multi-vehicle One-to-one Pickup and Delivery Problem with Split Loads (MPDPSL) aims to find itineraries for a homogeneous vehicle fleet in order to collect and deliver products to a set of geographically-distributed customers. The MPDPSL is defined as "one-to-one' since each product has a pre-assigned pickup and delivery location. The objective is to find minimum distance routes using at most all available vehicles, respecting capacity and maximum driving distance per vehicle, as well as precedence between pickups and deliveries. A customer may also be serviced by several vehicles, each one taking one part of the product. The MPDPSL is NP-hard and commonly found in practice, for example in parcel delivery services or car hauling applications. Combining pickups and deliveries with split loads leads to a difficult problem, even for neighborhood-centered heuristics, due to the large variety of possible service modes for each product. As a consequence few methods are available to address this problem.

To face this challenge, we propose a hybrid heuristic based on random variable neighborhood descent. The method relies on various local-search neighborhoods to cover all problem characteristics, combining changes of pickup locations, delivery locations, and load-splitting decisions. Larger neighborhoods are also considered, by reducing the problem of finding the best combination of pickup and deliveries with split loads – for one product – to a resource-constrained shortest path and solving it by dynamic programming. Extensive experiments demonstrate the excellent performance of the method on classic instances, since it outperformed all previous algorithms in similar computational time.

3 - PDPTW: a case study of a container transportation company

Thomas Van den Bossche, Tony Wauters, Jan Christiaens, Greet Vanden Berghe

In logistics and transportation many routing problems can be defined as pickup and delivery problems with time windows. In the present paper, one particular case is introduced in which a small fixed fleet of container barges needs to be routed on inland waterways. In contrast to the Liner Shipping problem, barges do not sail on a fixed schedule. Instead, a schedule is composed by considering the pickup and delivery intervals of all incoming orders within the planning horizon. Containers can be stacked in two or three layers, while the number of layers and the total container weight determine the barge's draft and thus the possibility to sail beneath bridges. Exchanging barges between towboats enables variability in barge capacity and therefore assists in generating cost-efficient routes. Additionally, the operator's inland location imposes extra constraints concerning lock waiting times and varying travel times. The operator's main goal is to offer high quality services with competitive costs in comparison with truck haulage. When the fleet capacity is insufficient for delivering all orders within the planning horizon, alternative means of transportation (i.e. truck haulage, leasing an extra barge) are necessary. However, these are more costly and are penalized accordingly. Real world data was provided by the container transportation company BCTN Meerhout. We present a heuristic approach to this problem. The optimization method is evaluated on the real data and experiments reveal competitive costs.

■ WA-03

Wednesday, 09:00-10:30 - HS 16

Rich VRPs 3

Stream: Rich VRPs
Chair: *Vera Hemmelmayr*

1 - Solving the Heterogeneous Vehicle Routing Problem with Time Windows and Site-Dependencies

Christian Doppstadt

We introduce a new optimization problem, combining the well-known Vehicle Routing Problem with Time Windows (VRPTW) with a heterogeneous fleet and a restricted accessibility of the customer locations, the so-called Site-Dependencies. To the best of our knowledge, this combination of restrictions has not been examined before. However, the Heterogeneous Vehicle Routing Problem with Time Windows and Site-Dependencies (HVRPTWSD) merges attributes with a high relevance for practical application in end-customer deliveries. As the problem is new, we introduce benchmark instances, which are based on the Solomon VRPTW instances and already include a heterogeneous fleet. For the site-dependencies, we add different levels with an increasing number of restrictions to visit a customer with a specific vehicle type. This combination of restrictions makes the HVRPTWSD very difficult to solve, as the number of valid solutions is limited. Therefore, we implemented a Tabu-Search, which is able to handle invalid solutions and guides the search process towards valid solutions by penalty values for the violation of any restriction. By a number of different numerical experiments, we test the functionality of our Tabu-Search. We are able to generate reasonably good solutions for a related problem, leaving out the site-dependencies. In addition, we are able to generate valid solutions for all of the instances we introduced, while meeting a relatively short calculation time.

2 - Column generation for the truck and trailer routing problem with time windows

Sophie Parragh, Jean-François Cordeau

Motivated by a field staff routing and scheduling problem faced by an infrastructure service provider in which subroutes have to be planned, we study the truck and trailer routing problem with time windows (TTRPTW). In the TTRPTW a fleet of trucks and trailers is routed in such a way that customers are visited within their time windows at minimum routing costs. Each customer has a certain demand and capacity limits of trucks as well as trailers have to be respected. Furthermore, certain accessibility restrictions apply: some customers can only be visited by a truck alone while others may be visited by a truck towing a trailer. At each of the latter customers, the trailer may be parked and a truck only subtour may be started. A trailer customer

serving as such a temporary depot may either be served before or after the subtour, whichever of the two is more advantageous in terms of the given time windows. We devise a path based formulation for the TTRPTW whose linear relaxation is solved by means of column generation. The resulting pricing subproblem corresponds to an elementary shortest path problem with resource constraints for which a dynamic programming based labeling algorithm is designed. Within the labeling algorithm certain problem properties, such as in which cases subtours should be generated, are exploited. In addition to the exact labeling algorithm, we also use heuristic pricing schemes. Furthermore, an initial set of columns is produced by means of large neighborhood search. We apply our column generation algorithm to instances derived from the well-known Solomon data set and we currently solve a number of instances with 25 customers and some instances with 50 customers within a time limit of two hours.

3 - An Adaptive and Diversified Vehicle Route Planning Approach to Reducing Security Risk of Cash-in-Transit Operations

Burcin Bozkaya, Sibel Salman, Kaan Telciler

Cash-in-Transit (CIT) transportation service operations involve picking up, transporting and delivering valuables (e.g. cash, securities, jewels, and other financial instruments) in secure vehicles among cash centers, bank branches, ATMs, jewelry stores, and retail stores. These services are typically provided by third-party providers that employ fleets of armored vehicles and guards. While the cost efficiency of these operations are essential to the service provider as well as the customer, equally important are the security risks associated with the operation. We recognize the CIT route-planning problem as a variant of the vehicle routing problem with pickup and deliveries (VRPPD), and with additional capacities and time windows. We additionally incorporate the risk element into the modeling and analysis of the routing problem to avoid potential undesirable incidents. We model risk to be composed of 1) risk due to repeated use of paths, which makes trucks easier targets, and 2) risk as trucks drive through low socio-economic status (SES) areas. Our solution approach includes the risk dimension in addition to travel cost minimization; hence it considers solving the problem from a bi-objective optimization point of view. We generate alternative short and dissimilar paths with varying distance and risk values, and then apply an adaptive and diversified randomized procedure for selecting alternative paths between pickup and delivery points. Our approach takes into account the past use of paths and hence attempts to reduce the incident risks over a period of multiple days. For each day, we solve a VRPPD using the Adaptive Large Neighborhood Search (ALNS) heuristic from the literature. We apply this approach on a real dataset obtained from a CIT service provider company operating in an industrial and urban region of Turkey, and report our results.

■ WA-04

Wednesday, 09:00-10:30 - HS 17

Urban Distribution

Stream: City Logistics
Chair: *Tal Raviv*

1 - Gasoline Delivery with Due Date Optimization

Rajan Batta

This talk will focus on optimizing gasoline delivery to gas stations in a community. The delivery price is a function of the due date window selected by the customers (gas stations). Customers select the due dates based on their inventory levels and delivery costs. Given due dates, the delivery company optimizes the delivery route. In turn, the delivery company can alter the delivery cost to due date relationship to minimize its overall delivery cost. A mathematical programming model that incorporates inventory cost considerations will be presented. It builds upon gasoline delivery routing work done by several researchers in recent years. The new feature is inventory consideration and the incorporation of delivery cost as a function of the due dates.

2 - Parking slot assignment for urban distribution: models and formulations

Mireia Roca-Riu, Elena Fernandez

Major cities face multiple problems caused by delivery operations in urban distribution. One goal of the City Council is to regulate the use of the public space to improve urban distribution. The adequate management of parking space, particularly loading and unloading areas is a key element in urban deliveries, as the lack of parking facilities has been pointed out among the aspects with higher impact in urban delivery. City Councils are responsible for regulating the conditions under which carriers may operate. In most cities some public space, consisting of a set of parking places, is allocated for loading and unloading operations during some hours each day. In general, space is scarce and must be shared among multiple stakeholders. Each carrier schedules his operations according to established rules and his resource limitations. An in-advance booking system able to be adjusted to user needs can be very useful for both City Councils and transport operators. Such a tool would assign requests to time slots according to their preferences, avoiding inefficiencies as the ones that arise when a freight carrier arrives to the delivery area but find no available parking space. Thus, carriers would greatly benefit from having a prebooked space. In turn, the City Council could prevent illegal parking and externalities caused by extra circulation of vehicles. Indeed, such a tool should be fed with criteria for allocating requests to time slots. We present the parking slot assignment problem for urban distribution. We introduce a basic model, which is mainly a feasibility problem, discuss alternative optimization criteria, and propose mathematical programming formulations. Some properties of the models are studied and relations among them are analyzed. Furthermore, we give a sufficient condition for unfeasibility of the basic model. Finally, we carry out an extensive computational experience, which provides quantitative indicators of the quality of each formulation.

3 - Optimal scheduling of mixed bus fleet
Tal Raviv, Yuval Elbar

Recently, cities have begun to incorporate battery-powered electric buses in their bus fleets. For example, Dan, the largest bus operator in the greater Tel Aviv area, declared its plan to acquire 200 electric buses in the next few years. The transition to electric buses is motivated by the technological evolution of high-capacity batteries for electric vehicles and the growing public awareness to the shortfalls of the currently prevailing diesel technology. Due to the risk involved in adapting new technologies and because the operational lifespan of diesel buses is 12-15 years, it is likely that the transition to electric buses will occur gradually. Therefore, for an extended period, there will be a need to plan the transit system operation of fleets that contains at least two types of buses. These two types have significantly different operational cost structures and range limitations. In particular, the operational range of electric buses is limited and thus, charging or battery-swapping operations should be included in their daily schedule. This study extends the classic bus scheduling models and solution methods to the more complex problem of scheduling mixed fleets. We formulate the model as an integer program and devise a branch-and-price algorithm to solve instances of moderate size. A math-heuristic that can solve larger instances are also presented. These solutions method are tested and compared using instances that are based actual time-tables.

Wednesday, 11:00-12:30

■ WB-01
Wednesday, 11:00-12:30 - HS 14

Network Design

Stream: Network Design
Chair: *Fabien Lehuédé*

1 - A Decomposition Heuristic for Inbound Lean Logistics
Michael Fry, Jeffrey Ohlmann

We consider the problem of designing a comprehensive plan for inbound logistics that faces a third-party logistics provider. We incorporate lean logistics principles into a heuristic approach that decomposes the decision of mode choice, cross-docking, visit frequency determination, and vehicle routing and scheduling.

2 - Dynamic Discrete Network Design Problem - Maintenance Planning for Traffic Networks
Pirmin Fontaine, Stefan Minner

We propose a dynamic bilevel model for network maintenance planning by extending the Discrete Network Design Problem. The leader decides over the maintenance period of the roads subject to budget constraints to decrease the congestion in the network, which is called the system-optimum. The follower, as in the Discrete Network Design Problem, optimizes the own path through the network, which is the user-optimum. We consider road deterioration over the periods, capacity reduction during maintenance and travel time improvement after the periods. The non-linear bilevel problem is first linearized and then transformed into a single-level mixed-integer program by using the Karush-Kuhn-Tucker conditions. This model is solved with Benders Decomposition, which is terminated after several iterations. The slave problem is further decomposed into independent subproblems, which can be solved in parallel. The numerical study shows that this method finds better solutions faster compared to the mixed-integer formulation and a genetic algorithm.

3 - A column generation approach for a pooled network design problem with piecewise linear cost structures
Fabien Lehuédé, Juliette Medina, Olivier Péton

The increasing competition in freight transportation market incites supply chain decision makers to set up new logistic models. Therefore, induced by cost rationalization, logistic performance and environmental objectives, many companies are involved in collaborative logistics projects for the supply or the distribution of their commodities. We consider a new service proposed by a third-party logistics company which develops an horizontal collaboration system between several companies in the retail area. Our main problematic is to design routes and load plans in a pooled network in order to maximize the overall efficiency of the system. Suppliers can pool their transports toward retailers via several shared cross-docks facilities. Pickup and delivery truck routes between suppliers and retailers improve the trucks fill rate. Route costs can be piecewise linear and depend on the distance and on the maximum load a truck carries during its journey. They can also depend only on the number of used trucks. We propose a column generation approach to solve this problem. We benchmark this method on a dataset based on real data from the French retail industry. In particular, we assess the impact of the cost structure on the column generation algorithm.

■ WB-02
Wednesday, 11:00-12:30 - HS 15

Maritime transportation

Stream: Waterway VRP
Chair: *Kjetil Fagerholt*

1 - Scheduling serial locks with combinatorial Benders' decomposition

Jannes Verstichel, Greet Vanden Berghe

Barges travelling on a network of inland waterways often have to pass several locks before reaching their destination. With the increasing share of waterbound multimodal transportation in the logistics chain, these inland locks are becoming a major bottleneck whose unpredictable service times may limit the long term viability of inland waterway transport. The aim of this research is to reduce the waiting times at locks while increasing the scheduling horizon of the entire chain of locks, thus overcoming the main downsides of waterbound transportation. Indeed, by not only reducing the total travel time but also offering accurate estimates of the expected travel time for each ship, waterbound transportation could well gain a significant boost in interest from industry, and become a competitive alternative for road and rail transportation.

We present a combinatorial Benders' decomposition approach that enables the incorporation of traffic dependent lock capacity into exact solution methods for the serial lock scheduling problem. The approach enables a highly efficient evaluation of the ship placement part of the lock scheduling problem in a sub problem, while tackling the lockage scheduling part in a reduced master problem. The method's performance is evaluated on a large set of small to medium sized instances, analysing the influence of traffic dependent lock capacities on both the ship waiting time and the total computation time. Despite promising results on small and medium sized instances, experiments show that the presented master problem is unable to tackle large real world instances. We therefore introduce a heuristic master problem of the presented combinatorial Benders' decomposition and discuss some preliminary results.

2 - Disruption management in offshore supply logistics

Kjetil Fagerholt, Magnus Stålhane

Significant costs and reduced service quality are caused by disruptions to planned routes and schedules for offshore supply vessels (OSVs) supplying oil and gas installations on the Norwegian continental shelf. The disruptions are mainly due to uncertain and potential harsh weather conditions, unexpected orders, and uncertain order volumes. We present a mathematical model for handling these disruptions, which becomes a version of the Pickup and Delivery Problem. The planning objective is to make decisions in order to get back to the plan within the next few days with as small negative consequences, both regarding costs and service, as possible. The decisions that we consider are rerouting the fleet of OSVs, short-term chartering of an additional OSV from the spot market, and postponing order deliveries. The model is implemented in commercial optimization software and tested on several instances based on real data from the oil and gas company Statoil. Since the results show that a commercial solver is able to solve small instances of the problem only, we also propose and test heuristic and exact solution methods, which are shown to give practical decision support for the real problem.

3 - A Heuristic for the Supply Vessel Planning Problem with Flexible Departures

Irina Gribkovskaia, Yauheni Kisialiou

We study a tactical supply vessel planning problem arising in the upstream offshore logistics. A fleet of vessels supplies a set of offshore installations from an onshore supply base on a planning horizon of one week. Each installation has a required visit frequency and daily opening hours for service. The problem involves finding a cost-minimal weekly schedule and a corresponding fleet composition satisfying base capacity and spread of departures constraints. The problem is originally studied with the fixed vessel departure times, reflecting the opening hours at the base, where voyages are defined by the sequences of installations visits, the starting days, and the durations in days. The two-phase solution approach ceases to find exact solutions for the medium-size instances with the fixed departure times, while the industry looks for the large-size problems solutions with the relaxed constraints on the departure times. We develop a large neighborhood search heuristic yielding weekly schedules with the flexible departure times. The basic logic of the algorithm includes multiple restarts, where at each restart the rearrangement of the broad part of initial solution takes place by the remove-insert procedure. Furthermore, several post-improvement procedures are applied to yield more cost-efficient solution. We test the heuristic performance on the instances of small and medium size by comparing them with the exact solutions, generated with the fixed and the flexible departure times. For the real large instances, the heuristic solutions generated with the flexible departure times are compared with the heuristic solutions found with the fixed departure times.

Wednesday, 11:00-12:30 - HS 16

Exact Solution of VRPs 3

Stream: Exact Solution of VRPs
Chair: *Timo Gschwind*

1 - The Vehicle Routing Problem with Release Dates

Claudia Archetti, Dominique Feillet, M. Grazia Speranza

In the literature on vehicle routing, arrival times of goods at the depot are not considered, i.e., it is typically supposed that all goods are available at the depot when the distribution is started. In this work, we study a vehicle routing problem where delivery routes have to be organized with the additional constraint that goods to be delivered are not all available at the depot at the start of the distribution phase. The routing problems should consider the additional issue of whether it is better to wait for additional goods to arrive and have a better loaded vehicle or to start a route of the vehicle with the currently available goods. We call this problem the Vehicle Routing Problem with release dates. We consider two special cases that are themselves declined in two variants: a case where a single vehicle is allowed to perform several trips during the time horizon (say, the day), one after the other, and a case where a fleet of vehicles is limited to a single route each. In both cases, capacity constraints are not considered. We call the first case the Traveling Salesman Problem with release dates (TSP-rd) while the second is called the Uncapacitated Vehicle Routing Problem with release dates (UVRP-rd). For both cases we consider a first variant where the objective is to minimize the total traveling distance in such a way that all customers are served within a deadline. The second variant we consider is the one where we minimize the completion time which is given by the sum of the total traveling time and the waiting time. Practical motivations for minimizing the completion time are the willingness to make the driver available as early as possible for further tasks or to avoid rush hours. Motivations to minimize the distance are related to cost or pollution minimization. We focus on the study of the computational complexity of the above mentioned problems on special graphs, namely the line and the star.

2 - Minimum Route Duration Algorithm for Traveling Salesman Problem with Multiple Time Windows

Jarosław Hurkała

The problem of finding minimum route duration plays important role in almost every variant of traveling salesman problem, vehicle routing problem, and orienteering problem, as well as their various extensions. The routing and scheduling problems with time windows gathered much attention because of their importance and practical use, and have been thoroughly studied. However, little has been done on problems with multiple time windows, which arise naturally in many practical situations. In this paper we propose a novel algorithm for computing the minimum route duration in TSP/VRP/OP problems with multiple time windows, and favorably compare it against three algorithms known in the literature. We prove that the proposed algorithm always produces optimal solutions, and show that it can also be seamlessly applied to problems with time-dependent travel and service time.

3 - Exact and heuristic solution methods for a VRP with time windows and variable service start time

Stefano Michelini, Hande Kucukaydin, Yasemin Arda, Yves Crama

We consider a VRP with time windows in which the total cost of a solution depends on the total duration of the vehicle routes, and the starting time for each vehicle is a decision variable. We first develop a Branch-and-Price (BP) algorithm considering the related pricing subproblem, an elementary shortest path problem with resource constraints (ESP-PRC). We discuss past, present and planned research on this exact solution methodology, based on a bidirectional dynamic programming approach for the ESPPRC, and on the design of a matheuristic.

Wednesday, 11:00-12:30 - HS 17

Scheduling

Stream: Scheduling
Chair: *Ulrike Ritzinger*

1 - Combined Vehicle Routing and Crew Scheduling with Hours of Service Regulations
Thibaut Vidal, Asvin Goel

Due to compulsory breaks and rests, total transit times between customer locations are usually much larger than the pure driving time. In Europe different hours of service regulations apply to trucks manned by a single driver and a team of two drivers. In the case of team driving, one driver can take a break while to other is driving, however, both drivers must take compulsory rest periods at the same time. In this contribution we study the problem of simultaneously determining the best assignment of drivers to vehicles, vehicle routes, and schedules complying with applicable regulations.

We present a hybrid heuristic combining a genetic algorithm for route optimisation with efficient labelling procedures for the generation of schedules. Computational experiments are conducted on variations of Solomon's benchmark instances for vehicle routing with time windows. Solutions are evaluated based on a cost function including fixed costs for vehicles, mileage costs, and driver wages. By varying these costs components, we seek to better understand how costs structures and instance characteristics, e.g. length of time windows and distribution of customers, impact the share of single and double manned vehicles. Furthermore, a comparison with best-known solutions for the single driver case is presented.

2 - A decompose-and-fix heuristic for driver rostering
Marta Mesquita, Margarida Moz, Ana Paias, Margarida Pato

Given a set of days-off schedules, defining feasible sequences of workdays and rest periods, the driver rostering problem (DRP) aims at determining the set of drivers to assign to each days-off schedule and the set of crew duties to be assigned to each driver, while ensuring transport demand and complying with labor and institutional norms. We show that the DRP is NP-hard and propose three MILP formulations to solve it: an assignment/covering model, a multi-commodity flow model and a mixed multi-commodity assignment model. Lower bounds obtained from the linear relaxations of the three models are compared from a theoretical point of view. Based on a hierarchy of the decisions made during the resolution of the problem, a decompose-and-fix heuristic is developed by exploring the underlying structure of the multi-commodity flow models. First, a pure multi-commodity flow problem is solved to determine a set of active schedules, and the minimum number of drivers, that cover all daily crew duties. Second, a greedy heuristic optimally assigns drivers to the schedules determined in step one, so as to minimize salary costs. Third, a branch-and-bound algorithm assigns daily crew duties to specific drivers ensuring the balance of the workload. Computational experience is presented and discussed.

3 - Bi-objective orienteering for personal activity scheduling
Piotr Matl, Pamela Nolz, Ulrike Ritzinger, Mario Ruthmair, Fabien Tricoire

We propose and solve a rich, bi-objective extension of the orienteering problem with time windows (OPTW) to model a combined routing and scheduling problem. Our research is motivated by the problem faced by mobile entrepreneurs, who have to integrate irregular appointments and tasks into their daily routines.

Self-employed people have a number of tasks which they need to perform at various locations (e.g. meetings with different clients), subject to varying time constraints (e.g. opening hours), and with different levels of importance or urgency (e.g. submitting a deliverable versus cleaning the home office). This corresponds to the OPTW. However, individual tasks may have several locations to choose from (e.g. packages may be sent from any post office), and these locations may have multiple time windows during the planning horizon. Furthermore, sets of related tasks may be subject to precedence relations (e.g. consecutive stages of a larger project), and it may be necessary to respect minimum and/or maximum time delays between some tasks (e.g. a day of rest between exercise sessions). We explicitly consider the trade-off between planning more tasks and enjoying more free time by means of a bi-objective model so that different preferences of decision makers can be taken into account.

We call this problem the Personal Planning Problem (PPP) and provide a mathematical formulation. A metaheuristic based on Large Neighborhood Search (LNS) is developed to generate a set of non-dominated solutions to the problem. We analyze solution quality on real-world-inspired test instances. Exact reference sets computed using a linearized single commodity flow model are used as benchmarks. Computational experiments show that the proposed metaheuristic generates near-optimal solution fronts and scales well to larger instances.

Wednesday, 14:00-15:30

■ WC-01
Wednesday, 14:00-15:30 - HS 14

Rich VRPs 4

Stream: Rich VRPs
Chair: *Philip Kilby*

1 - A Granular Search Algorithm for the Vehicle Routing Problem with Time Windows
Daniele Vigo, Michael Schneider, Fabian Schwahn

The use of granular neighborhoods is one way to improve the runtime of local-search-based metaheuristics for combinatorial optimization problems without compromising solution quality. More precisely, sparsification methods are applied to restrict the neighborhoods so that they include only elements which are likely to be part of high-quality solutions. The goal of this work is to provide insights about the design of effective and efficient granular solution methods for routing problems with time windows. We perform extensive numerical experiments with a granular tabu search (GTS) for the vehicle-routing problem with time windows (VRPTW) and we find that sparsification methods using reduced-cost values based on the solution of a linear relaxation of the original problem outperform standard sparsification methods. We also analyzed in depth additional features related to the effective use of granular neighborhoods in local search such as the role of depot arcs, the control on the number of incident arcs in specific vertices, the dynamic sparsification and the construction of more sophisticated sparse neighborhoods. The usefulness of the gained insights about the design of granular solution methods is demonstrated by the performance of the developed GTS for VRPTW, which obtains state-of-the-art results and reaches a considerable computational efficiency. With an average run-time of three seconds on a standard desktop computer, our GTS proves to be the fastest method in the literature that is able to find the best-known cumulative number of vehicles of 405 (evaluated as best of five runs) on the well-known Solomon VRPTW instances.

2 - There's more than one way to solve a long-haul transportation problem
Philip Kilby, Ignasi Abio, Daniel Guimarans, Daniel Harabor, Patrik Haslum, Valentin Mayer-Eichberger, Afzal Siddiqui, Sylvie Thiebaux, Tommaso Urli

It is said that there is more than one way to skin a cat. The same is true of solving long-haul transportation problems. We explore seven different approaches for solving a real-world multi-commodity long-haul transportation problem. The problem features a heterogeneous fleet with capacity constraints, compatibility constraints between commodities and trucks (e.g., refrigerated goods can only travel on refrigerated trucks), and demands which require split deliveries.

The problem has been studied at the request of a Queensland-based transportation company, which provided historical data concerning orders, and fleet data.

Among the explored approaches are: an educated random sampling coupled with a nearest-neighbour heuristic, a step-based constraint programming approach, a route selection approach which relies on a custom pre-processing phase, an answer set programming formulation, a large neighborhood search approach based on the classic vehicle routing formulation, an integer linear-programming method based on a set covering formulation, and an AI planning formulation.

We compare the results of the various approaches across a set of daily demands collected over a year, highlighting the weaknesses and strengths of the various approaches regarding aspects such as performance, flexibility, and scalability.

3 - Solving the Vehicle Routing Problem with Time Windows by the Bee Colony Optimization Algorithm
Milos Nikolic, Dusan Teodorovic, Milica Selmic, Bruce Golden

The vehicle routing problem with time windows is studied in this paper. We try to solve this well-known optimization problem by the relatively new metaheuristic called the Bee Colony Optimization (BCO). It

is shown that BCO can be applied effectively to solve difficult combinatorial problems. Our computational experiments show that the BCO is competitive with other methods and it can generate high-quality solutions with relatively small CPU times.

■ WC-02

Wednesday, 14:00-15:30 - HS 15

Pickup & Delivery 3

Stream: Pickup & Delivery
Chair: *Margaretha Gansterer*

1 - An Iterated Local Search Algorithm for the Pickup and Delivery Problem with Time Windows, Profits, and Reserved Requests
Yuan Li, Christian Prins, Haoxun Chen

The Pickup and Delivery Problem with Time Windows, Profits, and Reserved Requests (PDPTWPR) is a new variant of the Vehicle Routing Problem (VRP). In this problem, a set of identical vehicles located at a central depot must optimally be routed to serve a set of transportation requests, satisfying time windows, vehicle capacity and precedent constraints while maximizing the total profit. In the case of our study, a carrier has two types of requests to serve: reserved requests and selective requests. All reserved requests must be served due to its commitment to customers. Contrarily, selective requests are optional to serve. Each request is associated with a pickup and a delivery location and a specific service price. The PDPTWPR is NP-hard because the NP-hard PDPTW is its special case. Facing the high complexity of the PDPTWPR, we develop an Iterated Local Search (ILS) heuristic algorithm for this problem. The ILS is based on a rich neighborhood structure with 6 local search moves tailored to this problem: two intra-route moves (coupe-relocate and coupe-exchange), two inter-route moves (coupe-relocate and coupe-exchange), and a pair of remove/insertion operators of selective requests. These moves or operators are specifically designed to adapt the characteristics of the PDPTWPR. To evaluate to the performance of the ILS algorithm, a mixed-integer linear programming (MILP) model is formulated for the PDPTWPR. The solution found by the ILS is compared with the best solution of the model obtained by the Cplex solver in a given running time. The computational results show that the ILS outperforms the Cplex solver not only in terms of solution quality but also in terms of computational time.

2 - The Multi Vehicle Protable Pickup and Delivery Problem
Murat Küçüktepe, Margaretha Gansterer, Richard Hartl

The distribution market expands rapidly in a highly competitive environment. Logistic companies with insucient volume of transport capacities are forced to make a selection of customers that they can integrate eciently into their tours. Remaining customer requests can, for instance, be oered to collaboration partners in order to increase total prots. This is of particular relevance in the pickup and delivery market, where shipments from several dierent customers can be moved on one vehicle. We introduce the resulting planning problem as the Multi Vehicle Protable Pickup and Delivery Problem (MVPPDP). It refers to a central depot hosting multiple vehicles which transport goods from chosen pickup customers to the corresponding delivery customers within given travel time limits. We propose General Variable Neighborhood Search (GVNS) in order to produce good solutions for this problem. We conduct experiments with dierent variants of this method. Additionally, we compare it to an algorithm based on Guided Local Search (GLS), which is known to nd good solutions for related problems very fast. The performance of these methods is examined on the basis of data instances with up to 1,000 customer requests. In an experimental study a GVNS variant with a simple starting heuristic and 11 sequentially searched neighborhoods turns out to be the most favorable method to nd good solutions quickly.

3 - Hybrid column generation and large neighborhood search for the time-dependent selective PDPTW.
Peng Sun

The time-dependent selective pickup and delivery problem with time windows is the generalization to the case of pickup and delivery problem. In this problem, each request consists of a pickup location and a delivery location and a profits is collected from the visit to its pickup location. A limited amount of vehicles with capacity limit are available to serve the requests. The profit of a request can be collected by one vehicle at most. The objective is to determine a set of tours with departure times at a depot such that maximize the difference between the collected profits and the total routes duration cost. Time-dependent travel times are considered to capture road congestion. We propose a hybrid column generation and large neighborhood search algorithm for this problem. To show the effectiveness and efficiency of this method, we compare it with exact procedure and iterated local search metaheuristic method on a set of typical instances.

■ WC-03

Wednesday, 14:00-15:30 - HS 16

Dynamic VRPs

Stream: Dynamic VRPs
Chair: *Jeffrey Ohlmann*

1 - Dynamic freight selection for reducing long-haul round trip costs
Arturo Pérez Rivera, Martijn Mes

We consider a carrier that transports freight periodically, using long-haul round trips. At the start of a round trip, the carrier consolidates orders from a single origin for the long-haul and delivers them to multiple last-mile locations within a fixed destination area. Within this destination area, the carrier also picks up orders from various locations and consolidates them for the long-haul back to the origin. Since the long-hauls are always traveled, the locations that need to be visited for delivery and pickup determine the costs of each trip. Orders have time-windows within which the carrier must transport them to, or from, their locations. Orders become known gradually over time. However, there is probabilistic knowledge about future orders. Using this knowledge, the carrier can select, for each trip, the combination of orders which reduces costs over time (i.e., future trips). Orders are selected using a look-ahead consolidation policy, that is determined using an approximate dynamic programming (ADP) approach. This policy dictates which set of orders to transport in the next round trip, to minimize present and future (i.e., expected) costs. The approach is usable for different costs functions (i.e., cost as a function of chosen and not chosen orders) and for different transportation constraints. We test our approach in a series of simulation experiments based on data from a Dutch intermodal carrier. We discuss the strengths and weaknesses of our approach under different scenarios, and provide important managerial insights about consolidation of orders in long-haul round trips.

2 - A Microscopic Simulation Platform for Rich Dynamic Vehicle Routing Problems
Michal Maciejewski

Since modern transport services are becoming more flexible, demand-responsive, and energy/cost efficient, there is a growing demand for large-scale microscopic simulation platforms in order to test sophisticated routing algorithms. Such platforms have to simulate, in detail, not only the dynamically changing demand and supply of the relevant service, but also traffic flow and other relevant transport services. To address the problem above, the DVRP extension has been developed for the open-source MATSim simulator. The extension is designed to be highly general and customizable to simulate a wide range of dynamic rich vehicle routing problems. The model is capable of representing one-to-many and many-to-many topologies with nonhomogeneous vehicles, multiple depots, time widows, network-based routing and time-dependent stochastic travel times/costs. The model can be extended even further to cover other specific cases. Since online optimization is the central focus, the DVRP extension architecture allows plugging in of various algorithms. The algorithm reacts to selected events, such as request submissions or vehicle arrivals. Additionally, it can monitor the movement of individual vehicles or query other sources of online information. In response to changes in the system, the optimizer may re-optimize routes. Drivers adjust to the new routes as soon as possible, including immediate vehicle diversion if necessary. For passenger transport, interactions between drivers, passengers and dispatchers are simulated in detail. The DVRP extension has been used in several research projects carried out by teams from different universities and research centres. Two of the projects focus on on-line dispatching of electric taxis in Berlin and Poznan. Another project deals

with design of Demand-Responsive Transport for the Australian twin towns of Yarrawonga and Mulwala. In a recently launched project, it is used for simulation of DRT in Stockholm, Tel Aviv and Leuven.

3 - Dynamic Orienteering Through a Queueing Network
Jeffrey Ohlmann, Shu Zhang, Barrett Thomas

We consider a orienteering problem in which the traveler may experience a stochastic wait time at each customer. In our motivating applications, the wait time results from the queuing of other individuals waiting to meet with the customer during her specified time window. At each epoch of the Markov decision process, the salesperson must decide whether to stay in the queue at the current customer or depart for another customer. The objective is to maximum the expected reward collected from meeting with a customer. We demonstrate the value of a dynamic solution obtained via a novel compound rollout algorithm compared to static a priori route.

■ WC-04
Wednesday, 14:00-15:30 - HS 17

Electric Vehicle Routing 2

Stream: Electric Vehicle Routing Problems
Chair: *Ornella Pisacane*

1 - A branch-and-price approach for an electric vehicle routing problem with time windows, load-dependent energy consumption and intermediate recharging stops
Stefan Frank, Henning Preis, Karl Nachtigall

In this talk we focus on the widely treated vehicle routing problem with time windows (VRPTW) and involve additional constraints for routing a fleet of battery electric vehicles (BEVs) which represents a challenging task. This stems from: (i) the limited autonomy of the BEVs, mainly because of its restricted driving range, (ii) the consideration of a load-dependent energy consumption, and (iii) the integration of possible and may be repeatedly utilized charging stops at dedicated locations, i.e., recharging at such stations. For this problem we present an exact solution approach, that is a branch-and-price-algorithm, several acceleration techniques, and conclusions.

2 - Electric Vehicle Routing Problem
Jane Lin, Wei Zhou

In this paper, we investigate an Electric Vehicle Routing Problem (EVRP), in which electric commercial vehicles with a limited range may recharge at a charging station during their daily delivery (and pickup) tours, assuming the charging station facilities are already in place in the service area. The proposed EVRP formulation minimizes the total generalized cost as the sum of travel time cost and energy cost, both a function of vehicle operating factors such as vehicle speed and load distribution on the route. Each customer has a demand either to be delivered or picked up. The locations of EV charging stations are known and within the routing area. There is no special requirement where the stations are located. There may also be a mix of charging technologies available at locations. Furthermore, each charging station may be visited multiple times as needed and there is a cost associated with the charging time. The EVRP finds the optimal routing strategy whose total cost (i.e., travel time cost + vehicle recharging time cost + energy cost) is minimized such that: (1) each customer is visited exactly once by one vehicle on its route; (2) each route starts and ends at the depot; (3) the total demand of the customers served on a route does not exceed the vehicle capacity; and (4) each EV may recharge its battery once or more if necessary to complete all the tasks on its route. In addition, our model considers (1) the effect of vehicle load (as a function of customer demand and visiting order) on energy (electricity) consumption; and (2) delivery and pick-up tasks, paired or unpaired, during routing.

3 - Solving the Electric Vehicle Routing Problem with Time Windows and Partial Recharges
Ornella Pisacane, Maurizio Bruglieri, Ferdinando Pezzella, Stefano Suraci

Electromobility aims promoting transportation solutions employing the Electric Vehicles (EVs) in place of the traditional internal combustion engine vehicles in order to reduce the harmful CO_2 emissions that are polluting more and more the big cities. In addition, the recent technological progresses concerning the EVs allow also partial battery recharges. In this context, the aim of our work is to efficiently route a fleet of EVs, exploiting such recent technological advancements, in order to handle a set of customers within their time windows. Each EV route starts/ends from/at a common depot. Moreover, along each route, intermediate stops at the recharging stations for (also partial) battery recharges are allowed. The problem, known as Electric Vehicle Routing Problem with Time Windows, is here mathematically formulated as a Mixed Integer Linear Program (MILP) with the aim of firstly minimizing the number of EVs used and then, of optimizing the total time spent by the EVs outside the depot i.e., the total recharging, traveling and waiting times. In order to handle the problem hardness and to find good quality solutions in real life settings, a matheuristic, based on the Variable Neighborhood Search, is proposed. Numerical results, carried out on some benchmark instances, are shown for the solutions found by both the proposed MILP and the matheuristic.

Wednesday, 15:45 - 16:45

■ WD-01

Wednesday, 15:45 - 16:45 - HS 14

Closing Session

Stream: VEROLOG PLENARY
Chair: *Karl Doerner*

Wednesday, 17:00-18:30

■ WE-01

Wednesday, 17:00-18:30 - HS 14

ELOCOT panel

Stream: VEROLOG PLENARY
Chair: *Jakob Puchinger*
Chair: *Martin Savelsbergh*
Chair: *Max Schachinger*
Chair: *Peter Wilbers*

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