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VeRoLog 2013 Committees

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Organizing Committee

Chris Potts, University of Southampton, UK (Chair)

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Tolga Bektaş, University of Southampton, UK
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Conference Secretariat, Arash Mostajeran Gourtani, University of Southampton, UK

Foreword

On behalf of the local Organizing Committee, I would like to welcome you to the University of Southampton and the VeRoLog 2013 conference.

Southampton is the largest city on the south coast of England and has a population close to a quarter of a million. Southampton is a major port, which was the original point of departure for the Pilgrim Fathers aboard the Mayflower in 1620. The Titanic sailed from here, and the city contains several memorials and museum exhibitions related to the Titanic; most of crew having come from the city. Southampton remains an important ocean liner port frequented by luxury ships such as the QE2, Queen Mary 2, Queen Victoria, Arcadia, Oceana and many others.

The University dates back to 1862 when the Hartley Institution, as it was originally known, was established in the centre of Southampton. The Hartley Institution became Hartley University College and moved out of the city centre in 1919. It received its Royal Charter to award degrees and became the University of Southampton 1952. Today it is has about 25,000 students and has many world-leading departments.

VeRoLog 2013 is being organized by our research centre, CORMSIS (Centre for Operational Research, Management Science and Information Systems). CORMSIS is mainly made up from the Operational Research (OR) Group in the School of Mathematics and the Management Science (MS) Group in the School of Management. With about 30 academic staff, CORMSIS is one of the largest OR/MS groups within the UK.

During the preparation of this booklet, we learnt of the untimely death of Arne Løkketangen at the TRISTAN VIII conference in June. Arne had an established reputation in vehicle routing and metaheuristics and participated in the VeRoLog 2012 conference. We dedicate Verolog 2013 to his memory.

I hope that VeRoLog 2013 will follow the example of the first VeRoLog conference held last year in Bologna in allowing you to learn about new results research directions through our exciting programme of presentations, and to develop existing collaborations and form new ones.

I wish you all a pleasant stay in Southampton, and an enjoyable and stimulating conference.

Chris Potts
Chair of the Organizing Committee

General Information

Registration and Welcome Reception

Registration for VeRoLog 2013 and a welcome reception take place in Building 58a (School of Management Executive Education Building) in Salisbury Road from 19.00 on Sunday 7 July. There will also be a registration desk on Monday 8 July from 8.30 to 10.00 in Mathematics (Building 54).

The reception is sponsored by the Southampton Marine and Maritime Institute (SMMI), which is a unique internationally recognized centre of excellence, bringing together research, innovation and education communities from universities, research institutes, industry and governments. SMMI is a cross-disciplinary centre covering humanities, natural sciences, physical sciences and social sciences where knowledge acquisition and application is achieved in a collaborative manner with business, civic and industrial societies in order to reach our common objectives. We are grateful to SMMI for their generosity in supporting the welcome reception.

Location of sessions

All plenary talks, including the Opening Session and Panel Discussion, take place in Mathematics, Building 54, Lecture Theatre 4A (Room 4001). All parallel sessions take place in the Nuffield Theatre, Building 6.

The LANCS Initiative has provided financial support for our eminent invited speakers. The LANCS Initiative is a collaboration between Lancaster, Nottingham, Cardiff and Southampton Universities aimed at strengthening and growing theoretical Operational Research in the UK. A £13M investment is being used to achieve these goals. One of the research clusters of the LANCS Initiative is on Transport and Logistics, and members of this cluster have participated in the Programme and Organizing Committees of VeRoLog 2013.

Location of lunch and coffee breaks

Coffee and lunch breaks are held in the Garden Court, Building 40.

VeRoLog Help Desk

During the breaks, a VeRoLog help/information desk will be available in the Nuffield Theatre.

Internet Access

Internet access is available through Eduroam. Alternatively, we can provide guest login accounts for the University of Southampton network.

Unilink Buses

At registration, we will provide a bus ticket that allows unlimited travel on all Unilink buses. There are frequent services between the City and the University.

Social Program

Welcome Reception

- Date and time: Sunday, July 7, 19:00–21:00.
- Place: Building 58a (School of Management Executive Education Building), Salisbury Road.

City Walls Tour and Dinner Option

- Date and time: Monday, July 8, 18:30–19:30.
- Place: A guided tour of Southampton's city walls.
- Meeting point: Southampton Bargate (on High Street in the City Centre; take Unilink bus U1C or U6C).
- Comment: After the tour, there will be an opportunity to join one of the several dinners groups at different restaurants (but participants have to pay for their own dinner).

Excursion and Social Dinner

- Date and time: Tuesday, July 9, 15:00–23:00.
- Place: Visit to Stonehenge and Salisbury Cathedral.
- Meeting point: Campus interchange bus stop. Buses will leave at 15:00.

Maps

Program at a Glance

Monday	
9:00–9:45	Opening Session*
9:45–10:45	Plenary P1*
10:45–11:15	Coffee Break
11:15–13:00	M1
13:00–14:00	Lunch
14:00–15:45	M2
15:45–16:15	Coffee Break
16:15–17:15	Plenary P2*
18:30–19:30	Walls Walk

Tuesday	
9:00–10:45	T1
10:45–11:15	Coffee Break
11:15–12:15	Panel Discussion*
12:15–13:15	Lunch
13:15–15:00	T2
15:00–19:30	Excursion
19:30–22:30	Social Dinner

Wednesday	
9:00–10:45	W1
10:45–11:15	Coffee Break
11:15–12:30	Plenary P3*
12:30–13:30	Lunch
13:30–15:15	W2

* To be held in Mathematics, Building 54, Room 4001 (Lecture Theatre 4A).

Sessions M1, M2, T1, T2, W1, W2 to be held in the Nuffield Theatre, Bullding 6.

Sessions

Session M1

Session M1A: Exact Methods - 1

Time: 11:15-13:00 **Room:** Nuffield Theatre - B6, Room 1077 **Chair:** Stefan Røpke

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1. The Single Vehicle Dial-A-Ride Problem

   Enrico Bartolini
   Aristide Mingozzi

2. On One Class of Routing Optimization Problems

   Efim Bronshtein
   Ramiz Gindullin

3. Branch-Cut-and-Price for the Pickup and Delivery Problem with Time Windows and LIFO Loading

   Marilène Cherkesly
   Guy Desaulniers
   Gilbert Laporte

4. A Branch-and-Cut Algorithm for the Close-Enough Directed Arc Routing Problem

   Ángel Corberán
   Thais Ávila
   Isaac Plana
   José Mara Sanchis

Session M1B: Green Vehicle Routing - 1

Time: 11:15-13:00 **Room:** Nuffield Theatre - B6, Room 1081 **Chair:** Tom van Woensel

1. The Time-Dependent Pollution-Routing Problem

   Anna Franceschetti
   Dorothée Honhon, Tom Van Woensel
   Tolga Bektaş
   Gilbert Laporte

2. Parking Reservations in Shared Mobility Systems

   Mor Kaspi
   Tal Raviv
   Michal Tzur

3. An Evolutionary Algorithm for the Heterogeneous Fleet Pollution-Routing Problem

   Çağrı Koç
   Tolga Bektaş
   Ola Jabali
   Gilbert Laporte

4. Synchromodal Transport Planning

   Martijn Mes
   Rick van Urk

Session M1C: Clusterings and Metaheuristics

Time: 11:15-13:00 **Room:** Nuffield Theatre - B6, Room 1083 **Chair:** Philip Welch

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1. Clustering Customers in the VRPTW with Multiple Service Workers

   Gerald Senarclens de Grancy
   Marc Reimann

2. A Meta-heuristic Algorithm for a Split Delivery Vehicle Routing Problem with Clustered Backhauls

   Massimo Di Francesco
   Michela Lai
   Maria Battarra

3. Towards a General Meta-Heuristic Optimiser for Vehicle Routing: Experiments on Six VRP Types

   Philip Welch
   Anikó Ekárt

4. Feasible Insertion Genetic Algorithm for VRP with Constraints

   Gintaras Vaira
   Olga Kurasova

Session M1D: Column Generation and Heuristics

Time: 11:15-13:00 **Room:** Nuffield Theatre - B6, Room 1129 **Chair:** Boadu Mensah Sarpong

1. Route First Cluster Second-Based Formulations for a Variety of Routing Problems

   Mouaouia Cherif Bouzid
   Hacene Ait Haddadene
   Said Salhi

2. A Comparison of Different Column-Generation Formulations for the Pickup-and-Delivery Problem with Static and Dynamic Time Windows

   Timo Gschwind

3. Column Generation for the Bi-Objective Multi-Vehicle Covering Tour Problem

   Boadu Mensah Sarpong
   Christian Artigues
   Nicolas Jozefowiez

4. Two Approximation Methods for Bi-Objective Combinatorial Optimization: Application to the TSP with Profits

   Carlo Filippi
   Elisa Stevanato

Session M2

Session M2A: Neighbourhood Search

Time: 14:00-15:45 **Room:** Nuffield Theatre - B6, Room 1077 **Chair:** Olli Bräysy

1. A Simple Parameter-Free Heuristic for the Fleet Size and Mix Problem with Time Windows

   Olli Bräysy
   Wout Dullaert

2. A LNS for the 2E-CVRP

   Ulrich Breunig
   Verena Schmid
   Richard F. Hartl

3. Neighborhood Search Approaches for a Vehicle Routing Problem with Multiple Trips and Driver Shifts

   Véronique François
   Yasemin Arda
   Yves Crama

4. A Powerful Large Neighborhood Search for the Vehicle Routing Problem with Time Windows

   David Mester
   Olli Bräysy
   Wout Dullaert

Session M2B: Heuristic Algorithms

Time: 14:00-15:45 **Room:** Nuffield Theatre - B6, Room 1081 **Chair:** Stefan Irnich

1. A Destroy and Repair Search Heuristic for the School Bus Routing and Scheduling Problem with Transfers

   Michael Bögl
   Karl F. Doerner
   Sophie N. Parragh

2. A Set-Covering Based Heuristic for Rich Vehicle Routing Problems with a heterogeneous fleet

   Felix Brandt
   Nitin Ahuja
   Werner Heid
   Anne Meyer
   Frank Radaschewski

3. Efficient Local Search for the CARP with Combined Exponential and Classical Neighborhoods

   Stefan Irnich

4. A Hybrid Algorithm for the Split Delivery Vehicle Routing Problem

   Alexey Khmelev
   Yuri Kochetov

Session M2C: Electric Vehicles

Time: 14:00-15:45 **Room:** Nuffield Theatre - B6, Room 1083 **Chair:** Michael Schneider

1. The Hybrid Electric Vehicle Traveling Salesman Problem

   Christian Doppstadt

2. Routing of Electric Vehicles: Case Study of City Distribution in Copenhagen

   Esben Linde
   Allan Larsen
   Anders Vedsted Nørrelund
   Stefan Ropke
   Min Wen

3. A Math-Heuristic for the Green Vehicle Routing Problem

   Simona Mancini
   Guido Perboli
   Roberto Tadei

4. The Electric Vehicle Routing Problem with Time Windows and Mixed Fleet

   Michael Schneider
   Dominik Goeke

Session M2D: Shortest Paths and Other VRPs

Time: 14:00-15:45 **Room:** Nuffield Theatre - B6, Room 1129 **Chair:** Claudio Gambella

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1. Modern Shortest Path Algorithms in Practice

   Frank Schulz

2. Optimization of Service Start Time for an Elementary Shortest Path Problem

   Hande Küçükaydın
   Yasemin Arda
   Yves Crama

3. A Metaheuristic Approach for a Vehicle Routing Problem Arising in a Real Used-Oil Collection Project

   Roberto Montemanni
   Matteo Salani
   Dennis Weyland
   Luca Maria Gambardella

4. Exact and Heuristic Solutions of the Carrier-Vehicle Travelling Salesman Problem

   Claudio Gambella
   Andrea Lodi
   Daniele Vigo

Session T1

Session T1A: Time Dependent VRP

Time: 09:00-10:45 **Room:** Nuffield Theatre - B6, Room 1077 **Chair:** Gianpaolo Ghiani

1. A Fast and Exact Routing Engine for Large Dynamic Road Networks

   Daniel Delling
   Thomas Pajor
   Andrew Goldberg
   Renato Werneck

2. Construction Heuristic for a Vehicle Routing Problem with Time-Dependent Functions

   Alexander Kleff

3. The Time-Dependent Vehicle Routing Problem with Soft Time Windows and Stochastic Travel Times

   Duygu Taş
   Nico Dellaert
   Tom van Woensel
   Ton de Kok

4. A Lower Bound for the Point-to-Point Quickest Path Problem

   Emanuela Guerriero
   Gianpaolo Ghiani

Session T1B: General Applications - 1

Time: 09:00-10:45 **Room:** Nuffield Theatre - B6, Room 1081 **Chair:** Petrica Pop

1. Continuous Monitoring Problem for Disaster Management

   Vera Mersheeva
   Gerhard Friedrich

2. A Survey on Algorithmic Approaches to the Generalized Vehicle Routing Problem

   Petrică Pop
   Andrei Horvat-Marc
   Corina Pop Sitar

3. From VRP Research Toward GIS Prototype

   Sacha Varone
   Iliya Markov

4. Optimal Toll Enforcement — An Integration of Vehicle Routing and Duty Rostering

   Elmar Swarat
   Ralf Borndörfer
   Guillaume Sagnol

Session T1C: Green Vehicle Routing - 2

Time: 09:00-10:45 **Room:** Nuffield Theatre - B6, Room 1083 **Chair:** Tom van Woensel

1. Environmental Impacts of Intermodal Freight Transportation

   Emrah Demir
   Tom Van Woensel

2. Branch and Price for the Pollution-Routing Problem

   Tom Van Woensel
   Emrah Demir
   Said Dabia

3. Horizontal Cooperation in Multi-Vehicle Routing Problems with Environmental Criteria

   Angel A. Juan
   Javier Faulin
   Elena Pérez-Bernabeu

4. Offshore Windfarm Infield Cable Layout: Models and Algorithms

   Jens Lysgaard
   Joanna Bauer

Session T1D: Waste Collection and Earthwork Optimization

Time: 09:00-10:45 **Room:** Nuffield Theatre - B6, Room 1129 **Chair:** Stefano Novellani

1. A GRASP Algorithm for a Real-World Waste Collection Problem

   Ana Dolores López Sánchez
   Abraham Duarte
   Francisco Gortázar
   Alfredo G. Hernández-Díaz
   Miguel Ángel Hinojosa Ramos

2. Earthwork Optimization Models for the Construction of a Large Highway System

   Stefano Novellani
   Christian Bogenberger
   Mauro Dell'Amico
   Gerhard Hoefinger
   Manuel Iori
   Barbara Panicucci

3. Sectors Design for Waste Collection Routing

   Ana Maria Rodrigues
   José Soeiro Ferreira

4. Residential Waste Collection in Urban Environments

   Dimitris Paraskevopoulos
   Panagiotis Repoussis
   Christos Tarantilis

Session T2

Session T2A: Maritime Applications

Time: 13:15-15:00 **Room:** Nuffield Theatre - B6, Room 1077 **Chair:** Kjetil Fagerholt

1. Oil Platform Transport Problem (OPTP)

   Ocotlán Díaz-Parra
   Jorge A. Ruiz-Vanoye
   María de los Ángeles Buenabad Arias

2. Fleet Deployment and Speed Optimization in RoRo Shipping

   Kjetil Fagerholt
   Henrik Andersson
   Kirsti Hobbesland

3. Tonnage Allocation in Dry Bulk Liner Shipping

   Bjørn Nygreen
   Øydis Kristine Flateby
   Inge Norstad

4. A Contraction-Expansion Algorithm for the Capacitated Minimum Cost Flow Problem

   Jean-Bertrand Gauthier
   Jacques Desrosiers
   Marco E. Lübbecke

Session T2B: Exact Methods - 2

Time: 13:15-15:00 **Room:** Nuffield Theatre - B6, Room 1081 **Chair:** Stefan Ropke

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1. A Column Generation Approach for Strategic Planning in LTL Logistics

   J. Fabian Meier
   Frank Baumann
   Christoph Buchheim
   Uwe Clausen

2. Solving the Solomon Instances: The Importance of Branching Decisions

   Stefan Ropke

3. Single-Item Reformulations for a Vendor Managed Inventory Routing Problem

   Pasquale Avella
   Maurizio Boccia
   Laurence A. Wolsey

4. An Exact Algorithm for the Robust Stochastic Inventory Routing Problem with Outsourced Transportation

   Demetrio Laganà
   Luca Bertazzi
   Adamo Bosco

Session T2C: Travelling Purchaser and Multitrip Problems

Time: 13:15-15:00 **Room:** Nuffield Theatre - B6, Room 1083 **Chair:** Nicola Bianchessi

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1. The Distance Constrained Multiple Vehicle Traveling Purchaser Problem

   Nicola Bianchessi
   Renata Mansini
   M. Grazia Speranza

2. Multi-Vehicle Travelling Purchaser Problem with Exclusionary Side Constraints

   Daniele Manerba
   Renata Mansini

3. The Stochastic and Dynamic Traveling Purchaser Problem

   Renata Mansini
   Enrico Angelelli
   Michele Vindigni

4. The Multi Trip Vehicle Routing Problem with Time Windows and Release Dates

   Diego Cattaruzza
   Nabil Absi
   Dominique Feillet

Session T2D: Electric Vehicles and Other Applications

Time: 13:15-15:00 **Room:** Nuffield Theatre - B6, Room 1129 **Chair:** Michael Schneider

1. Formulations for the Station Location Problem for Electric Vehicles

   Min Wen
   Gilbert Laporte
   Oli B.G. Madsen
   Anders V. Nørrelund
   Allan Olsen

2. The Electric Fleet Size and Mix Vehicle Routing Problem with Time Windows

   Gerhard Hiermann
   Jakob Puchinger
   Richard F. Hartl

3. A Genetic Algorithm Approach to Solve the Team Orienteering Problem — Comparing Different Solution Strategies

   João A. O. Ferreira
   José A. Oliveira
   Luís S. Dias
   Guilherme A. B. Pereira

4. A Heuristic Approach to the Urban Transit Routing Problem

   Matthew John

Session W1

Session W1A: Exact Methods - 3

Time: 9:00-10:45 **Room:** Nuffield Theatre - B6, Room 1077 **Chair:** Stefan Ropke

1. Bound Sets for the Biobjective Team Orienteering Problem with Time Windows

   Fabien Tricoire
   Sophie N. Parragh

2. Facing the Parking Areas Problem for Dangerous Goods in the European Road Transport Network

   Maria Dolores Caro
   Eugenio M. Fedriani
   Ángel F. Tenorio

3. A Branch-and-Price Algorithm for the Fixed Charge Transportation Problem Based on a New Mathematical Formulation

   Roberto Roberti
   Enrico Bartolini
   Aristide Mingozzi

4. The Double Vehicle Routing Problem with Multiple Stacks

   María Batista-Galván
   Jorge Riera-Ledesma

Session W1B: Rural Postman and Arc Routing

Time: 9:00-10:45 **Room:** Nuffield Theatre - B6, Room 1081 **Chair:** Claudia Archetti

1. Territory-Based Vehicle Routing in the Presence of Time Window Constraints

   Daniele Vigo
   Michael Schneider
   Andreas Stenger
   Fabian Schwann

2. On the Generalized Directed Rural Postman Problem

   Michael Drexl

3. Reoptimizing the Rural Postman Problem

   Claudia Archetti
   Gianfranco Guastaroba
   M. Grazia Speranza

4. Arc Routing Solutions to a Case Study

   Maria Cândida Mourão
   Leonor Santiago Pinto

Session W1C: VRP with Inventories

Time: 9:00-10:45 **Room:** Nuffield Theatre - B6, Room 1083 **Chair:** Leandro Coelho

1. Vehicle Routing with Vendor Selection, Intermediate Pickups and Deliveries

   Uğur Emec
   Bülent Çatay
   Burçin Bozkaya

2. An Optimized Target Level Inventory Replenishment Policy for Vendor-Managed Inventory Systems

   Leandro C. Coelho
   Gilbert Laporte

3. Supply of Liquid Petroleum Gas to Fuel Stations — An Example of Carrier Managed Inventory Replenishment

   Pawel Hanczar

4. Synchronization in Vehicle Routing: Starting Time Coordination for Operations from Different Routes

   Jörn Schönberger

Session W1D: Healthcare Applications

Time: 9:00-10:45 **Room:** Nuffield Theatre - B6, Room 1129 **Chair:** Maciek Nowak

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1. Planning of Home Health Care Transport Services with Subroutes and Interdependencies

   Christian Fikar
   Patrick Hirsch

2. Estimating the Cost of Continuity of Care in Home Health Care Delivery

   Maciek Nowak
   Mike Hewitt

3. Periodic Vehicle Routing Problem for Blood Distribution

   Pornpimol Chaiwuttisak
   Honora Smith
   Yue Wu

4. Optimization of Patient Transportation — Solving an Extension of the Heterogeneous Multi Depot Dial-A-Ride Problem with Tabu Search Variants

   Marco Oberscheider
   Patrick Hirsch

Session W2

Session W2A: General Applications - 2

Time: 13:30-15:15 **Room:** Nuffield Theatre - B6, Room 1077 **Chair:** Maged Dessouky

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1. A Pickup and Delivery Problem for Ridesharing Considering Congestion

   Xiaoqing Wang
   Maged Dessouky
   Fernando Ordonez

2. Kernel Search for Capacitated Facility Location Problems

   Gianfranco Guastaroba
   M.Grazia Speranza

3. Constructing Solution Attractor for Probabilistic Travelling Salesman Problem through Simulation

   Weiqi Li

4. Anticipatory Optimization for Routing in the Euclidean Plane

   Marlin W. Ulmer
   Dirk C. Mattfeld

Session W2B: General Applications - 3

Time: 13:30-15:15 **Room:** Nuffield Theatre - B6, Room 1081 **Chair:** Patrick Beullens

1. Rich and Real-Life Vehicle Routing Problems: Cases of Study in Spain

   José Cáceres Cruz
   Daniel Riera, Angel Juan
   Helena R. Lourenço, Alex Grasas
   Roman Buil

2. The Recurring Fleet Size and Mix Vehicle Routing Problem (R-FSMVRP)

   Urooj Pasha
   Arild Hoff
   Arne Løkketangen

3. Do Cash-Flows Matter in Inventory-Routing Problems?

   Patrick Beullens

4. Split-Based Metaheuristic for the Multitrip Cumulative Capacitated Vehicle Routing Problem

   Juan Carlos Rivera
   H. Murat Afsar
   Christian Prins

Session W2C: General Applications - 4

Time: 13:30-15:15 **Room:** Nuffield Theatre - B6, Room 1083 **Chair:** Geir Hasle

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1. Efficient Local Search for a Capacitated Vehicle Routing Problem with Due Dates and Batch-Availability Constraints

   Benjamin C. Shelbourne
   Chris N. Potts
   Maria Battarra

2. A Cycle-Based Evolutionary Algorithm for the Multi-Commodity Network Design Problem

   Dimitris Paraskevopoulos
   Tolga Bektaş
   Teodor Gabriel Crainic
   Chris Potts

3. Transfer Synchronisation in Multimodal Corridors

   Hanne L. Petersen
   Federico Farina
   Rune Larsen
   Allan Olsen

4. Solving Routing Problems with the GPU

   Geir Hasle
   Torkel Haufmann
   Christian Schulz

Session W2D: Metaheuristics and Neighbourhoods

Time: 13:30-15:15 **Room:** Nuffield Theatre - B6, Room 1129 **Chair:** Thibaut Vidal

1. Metaheuristics for the Clustered Vehicle Routing Problem

   Maria Battarra
   Güneş Erdoğan
   Anand Subramanian
   Thibaut Vidal

2. Compound Neighborhood Structures for Heterogeneous Vehicle Routing Problems

   Puca Huachi Vaz Penna
   Thibaut Vidal
   Anand Subramanian
   Luiz Satoru Ochi
   Christian Prins

3. On Unified Methods for Multi-Attribute VRPs, Route Evaluation Operators and Large Neighborhoods

   Thibaut Vidal
   Teodor Gabriel Crainic
   Michel Gendreau
   Christian Prins

4. Heuristics for the Team Orienteering Problem with Time Windows and Flexible Fleet

   Fraser McLeod
   Güneş Erdoğan
   Tom Cherrett
   Tolga Bektaş

5. Constrained Dynamic Vehicle Routing Problem with Time Windows

   Jesica de Armas
   Belén Melián-Batista
   José A. Moreno-Pérez

Technical Programme Overview

Plenary Talks

Plenary P1: *Some Interesting Vehicle Routing Research Topics: Suggestions from an Oldtimer*
Bruce Golden
University of Maryland, USA
Monday, July 8th, 9:45–10:45, B54 / Room 4A

Plenary P2: *Multi-Commodity vs. Single-Commodity Routing*
Maria Grazia Speranza
University of Brescia, Italy
Monday, July 8th, 16:15–17:15, B54 / Room 4A

Plenary P3: *An Overview of Vehicle Routing with Pickup and Delivery*
Jean-François Cordeau
HEC Montréal, Canada
Wednesday, July 10th, 11:15–12:30, B54 / Room 4A

Plenary Talks

Some Interesting Vehicle Routing Research Topics: Suggestions from an Oldtimer

Bruce Golden *
University of Maryland, USA, `bgolden@rhsmith.umd.edu`

Those of us who attend Verolog and similar research conferences on a regular basis form a community of vehicle routing researchers. We are a tight-knit community. Collectively, we work on a wide variety of vehicle routing topics and we have had a definite and positive impact on distribution activities around the world. We should be proud of this. Some of us work on node routing, while others work on arc routing problems. A few of us dare to study general or mixed routing problems. Most of us assume a single objective function, but some work in a multi-objective environment. Some of us work on exact solution approaches and finding tight lower bounds using integer programming. Others develop heuristic or metaheuristic approaches to obtain good solutions to large problem instances. Some try to prove worst-case results for heuristics or identify examples of perverse heuristic behavior. Most of us use discrete mathematics in our research, but a few apply continuous mathematics. A few of us take advantage of parallel computing; most of us do not. In general, we recognize that all of these research streams are important, revealing, and complementary. Many of us work in different research streams over time.

Now, suppose we asked those who are vehicle routing software vendors to describe the research problems that they would have us work on, if we reported directly to them. These vendors receive requests for help with real-world vehicle routing on a daily basis. I have contacted about ten of these vendors. In my talk, I will discuss the specific and not-so-specific topics that were mentioned. Hopefully, between now and the next Verolog conference, we can begin to make progress with respect to at least some of these.

Multi-Commodity vs. Single-Commodity Routing

Maria Grazia Speranza *
University of Brescia, Italy, `speranza@eco.unibs.it`

In most of the literature on vehicle routing problems, a single numeric value expresses the demand of a customer. The typical constraint is that the total demand served by a vehicle cannot exceed the vehicle capacity. In this paper, we study the cost implications from using vehicles dedicated to a single commodity compared with using flexible vehicles capable of carrying any set of commodities. The problem we study has several important applications. A first category of applications is the one where different vehicles are available on the market, namely vehicles that are specific for a commodity and vehicles that are flexible and may be used for different commodities. Usually, the flexible vehicles are more expensive than the specific vehicles, and a decision has to be made about whether it is beneficial to invest in the flexible vehicles. A decision can be made only through the evaluation of the reduction of the operational costs due to the availability of the flexible vehicles with respect to the operational costs in case the specific vehicles are used. A second category of applications concerns the evaluation of the opportunity for companies to collaborate and share vehicles and customers. In this case, the vehicles of the different companies serve the same kind of commodity, but each company uses its own vehicles for its own customers. Is it beneficial for the companies to invest in a collaboration project and share vehicles and customers?

In the problem we study, we are given a set of geographically scattered customers, a set of commodities and an unlimited fleet of capacitated vehicles. Each vehicle starts from a depot, visits a set of customers and returns to the depot at the end of the tour. Any customer may demand delivery of any of the commodities. We assume that the total demand of a customer, though, does not exceed vehicle capacity. We will consider different situations, depending on whether a vehicle is dedicated to a commodity or is flexible and also depending on whether the demand of a customer may be satisfied by one or several vehicles. If the demand may be satisfied by more than one vehicle, we will examine when deliveries of individual commodities can be split and when they cannot. Each situation gives rise to a different optimization problem. Whereas most of these problems are known, one is new. We will compare these problem variants from a worst-case perspective and show that, while it is intuitive that it may be highly beneficial to use flexible vehicles, there are situations where it is beneficial to use dedicated vehicles. We will show that allowing the delivery of different commodities with different vehicles and allowing the splitting of the delivery of a commodity are, from the worst-case point of view, equally beneficial, i.e., they lead to the same worst-case bound. We will complement the worst-case analysis with a computational study to understand what problem characteristics yield different relative results for the problem variants.

An Overview of Vehicle Routing with Pickup and Delivery

Jean-François Cordeau *
HEC Montréal, Canada, `jean-francois.cordeau@hec.ca`

Pickup and delivery problems constitute an important family of vehicle routing problems in which goods or passengers must be transported from multiple origins to multiple destinations. These problems arise, among others, in urban courier operations, in forward and reverse logistics systems, and in dial-a-ride transportation services for the elderly and the disabled. There exist a large number of problem variants which have been the object of an equally abundant scientific literature. Several of these variants also have special combinatorial structures that can be exploited in the design of effective solution methods. This talk will provide an overview of the most important pickup and delivery problems and present the state of the art in terms of mathematical models and solution algorithms.

Abstracts of the presentations (ordered by first author)

Reoptimizing the Rural Postman Problem

Claudia Archetti*
Department of Economics and Management, University of Brescia, Italy, `archetti@eco.unibs.it`
Gianfranco Guastaroba
Department of Economics and Management, University of Brescia, Italy, `guastaroba@eco.unibs.it`
M. Grazia Speranza
Department of Economics and Management, University of Brescia, Italy, `speranza@eco.unibs.it`

Arc routing problems are vehicle routing problems where customers are represented by edges or arcs of a network. Such problems arise in a variety of practical contexts, such as street sweeping, garbage collection, mail delivery, meter reading or full truckload transportation. Even if they are much less studied than node routing problems, they recently inspired a rich and ever growing body of literature.

In this paper we consider the undirected Rural Postman Problem (RPP) which consists in determining a minimum cost cycle traversing at least once each edge belonging to a given subset of the edges of an undirected graph. The edges to be traversed are said to be *required.* In particular, we consider the reoptimization of the RPP, i.e., the problem incurred when a perturbation on a previously solved instance occurs.

More in details, we consider the following problem: Given an instance of the RPP together with an optimal solution, a perturbation of the instance takes place and a new instance has to be solved. We refer to this problem as the *reoptimization of the RPP.* We aim at exploiting the availability of an optimal solution of the original instance to find good solutions for the perturbed instance in an efficient manner, rather than running the optimization on the new instance from scratch. We consider two kinds of perturbations of the instance, namely the addition and the removal of one edge. In the case of one edge removal we address two cases separately, i.e. the case the edge is required and the case it is not. We analyze the computational complexity of the reoptimization problems. We prove that the considered reoptimization problems are $\mathcal{NP}$-hard. We propose simple approximation algorithms to solve them. We analyze the worst-case behavior of the approximation algorithms and show that they outperform in terms of running time other approximation algorithms for solving the RPP from scratch. Specifically, we show that a cheapest insertion algorithm has a worst-case ratio equal to 2 when used to insert the new edge into an optimal RPP tour. While the worst-case behavior is worse than the Frederickson algorithm [2], the computing time is linear instead of exponential in the number of connected components in the subgraph induced by the required edges (Dror [1]). Finally, we conjecture that the worst-case ratio is actually 3/2 and provide instance-related conditions under which the latter bound is tight.

We also introduce simple algorithms based on computing the shortest path between two nodes to tackle the problem of removing an edge from an RPP instance. The time complexity of the algorithms is polynomial, due to the computation of the shortest path (see Fredman and Tarjan [3]), and outperforms the Frederickson algorithm [2]. Moreover, we show that the approximation algorithms proposed to remove an edge guarantee a tight worst-case ratio equal to 3/2.

We perform computational experiments adapting benchmark RPP instances to the reoptimization problems. Computational results show the nodal importance of reoptimization both in terms of quality of the solution and efficiency of the computation.

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Single-Item Reformulations for a Vendor Managed Inventory Routing Problem

Pasquale Avella[*]
Dipartimento di Ingegneria, Universit del Sannio, `avella@unisannio.it`

Maurizio Boccia
Dipartimento di Ingegneria, Universit del Sannio,

Laurence A. Wolsey
CORE, Université catholique de Louvain,

The Inventory Routing Problem (IRP) involves the distribution of one or more products from a supplier to a set of customers over a discrete planning horizon. Each customer has a known demand to be met in each period and can hold a limited amount of stock. The product is shipped through a distribution network by one or more vehicles of limited capacity.

The version treated here, the so-called Vendor Managed Inventory Routing Problem (VMIRP) [1], is the Inventory Routing problem arising when replenishment policies are decided by the supplier. We consider two replenishment policies, both assuming that a stock upper bound is given for each customer. The first is known as Order-up (OU): if a customer is visited in a period, then the amount shipped to a client must bring the stock level up to the upper bound. The latter is called Maximum Level (ML): the stock level in each period cannot cannot exceed the upper bound.

The objective is to find replenishment decisions minimizing the sum of the storage and of the distribution costs. VMIRP contains two important subproblems: a lot-sizing problem for each client and a classical routing problem. We present a-priori reformulations of VMIRP-OU and VMIRP-ML derived from the single-item lot-sizing substructure. In addition we introduce some valid inequalities connecting the lot-sizing and the routing substructures based on the capacity of the vehicle and the OU replenishment policy.

The reformulation procedures have been embedded into a Branch-and-Cut framework to demonstrate their effectiveness. Computational results on benchmark instances with a single product and a single vehicle are presented.

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The Single Vehicle Dial-A-Ride Problem

Enrico Bartolini *
DISMI, University of Modena and Reggio Emilia, Italy, `enrico.bartolini@unimore.it`
Aristide Mingozzi
Department of Mathematics, University of Bologna, Italy, `aristide.mingozzi@unibo.it`

In the Single Vehicle Dial-A-Ride Problem (SVDARP), a vehicle located at a depot is required to service a set of user transportation requests each defined by a pair of origin and destination points, and a ride time. The problem is to design a least cost tour for the vehicle starting and ending at the depot, and picking up each request at the origin point before delivering it to the corresponding destination. Ride-time constraints impose that the time spent by the vehicle between the origin and destination nodes of each request is not greater than the request's ride time. In some applications, a load can also be associated with each request, and capacity constraints impose that the vehicle load cannot exceed the vehicle capacity. We consider both the capacitated and the not-capacitated SVDARP. We describe three mathematical formulations of the problem that are used to derive new lower bounds, and three exact methods. An extensive computational analysis on both capacitated and not-capacitated SVDARP instances shows that the proposed algorithms are capable of solving to optimality instances involving up to 50 requests.

The Double Vehicle Routing Problem with Multiple Stacks

María Batista-Galván*
Transportes Interurbanos de Tenerife, S.A.U., C/Punta de Anaga 1,38111 Santa Cruz de Tenerife, Spain, `mdbatista@titsa.com`

Jorge Riera-Ledesma
Universidad de La Laguna, Av. Astrofísico Francisco Sánchez s/n, 3271 La Laguna, Spain, `jriera@ull.edu.es`

The Double Traveling Salesman Problem with Multiple Stacks [1] (DTSPMS) is a pickup-and-delivery single-vehicle routing problem which performs the pickup operations before the deliveries, and loads the collected products into a capacitated vehicle as they are picked up. This problem arises when the pickup and delivery regions are widely separated, and the transportation cost between both regions is fixed and therefore not considered as part of the optimization problem.

The pickup and the delivery points, in addition to a depot in each region, are known in advance. There is a routing cost related to each pair of points for each region. Each product is associated exactly with a pickup point in the pickup region and with a delivery point in the delivery region. All products have identical shape and size, and the vehicle has a loading space divided into stacks of a fixed height. This loading space is big enough to store all products, and the loading operations follow a Last-In-First-Out (LIFO) policy. That means that each loaded product is placed at the top of one of those stacks, and only the products located at the top of a stack can be unloaded from the vehicle.

The DTSPMS collects each product following a Hamiltonian tour in the pickup region starting at the pickup depot, and delivers the products also following a Hamiltonian tour in the delivery region starting at the delivery depot. Note that, the LIFO policy determines the order of collection and delivery, therefore any description of both Hamiltonian tours should specify unambiguously the pickup and delivery sequence. The aim is to minimize the total routing cost satisfying the stacks height and the LIFO policy. Therefore, the DTSPMS combines two instances of the directed Traveling Salesman Problem, one for the pickup region and another for the delivery region, with a combinatorial loading problem. This loading problem establishes whether both tours are compatible with respect to the features of the vehicle container. A generalization of this problem considers the variation where a single container is not enough to collect all products and therefore more than one vehicle have to perform the collection and the delivery. This implies that the problem has to design multiple routes for the vehicles collecting and delivering the products.

We introduce and formulate this generalization, called the Double Vehicle Routing Problem with Multiple Stacks. We proposes a three index formulation and a set-covering formulation that have motivated a Branch-and-Cut algorithm and a Branch-and-Cut-and-Price algorithm, respectively. The performance of both algorithms has been studied on a wide family of benchmark test instances.

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Metaheuristics for the Clustered Vehicle Routing Problem

Maria Battarra*
Mathematics, University of Southampton, Highfield Southampton, SO17 1BJ,
`m.battarra@soton.ac.uk`

Güneş Erdoğan
Management, University of Southampton, Highfield Southampton, SO17 1BJ, `g.erdogan@soton.ac.uk`

Anand Subramanian
Universidade Federal da Paraíba, Departamento de Engenharia de Produção, Centro de Tecnologia, Campus I - Bloco G, Cidade Universitária, João Pessoa-PB, 58051-970, Brazil, `anand@ct.ufpb.br`

Thibaut Vidal
Universidade Federal Fluminense, Departamento de Engenharia de Produção, Rua Passo da Pátria 156, Bloco E-4º andar, São Domingos, Niterói-RJ, 24210-240, Brazil, `thibaut.vidal@cirrelt.ca`

The Clustered Vehicle Routing Problem is a variant of the Capacitated Vehicle Routing Problem in which customers are clustered. As in the CVRP, all the customers must be visited exactly once, but a vehicle visiting one customer in a cluster must visit all the remaining customers therein before leaving it.

The problem was recently introduced in Battarra et al. [1], where a comparative study of alternative exact algorithms are presented and examples of applications are provided. This study has shown how the cluster constraints allow for the solution of much larger instances than in the CVRP, and effective upper bounds can further improve the performance of the algorithms.

In this contribution, we aim to develop effective metaheuristic algorithms based on the Iterated Local Search and Memetic Algorithm frameworks. The problem is first solved as a CVRP by modifying the distance matrix. A large coefficient is added to edges connecting clusters as proposed in Barthélemy et al.[2]. Secondly, the proposed metaheuristics are adapted to take advantage of the cluster substructure, where the optimal Hamiltonian paths for each pair of endpoints in each cluster are precomputed, and the search is limited to the optimal sequence of clusters in each route. These metaheuristics are compared and extensive computational results will be presented.

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Do Cash-Flows Matter in Inventory-Routing Problems?

Patrick Beullens*
Mathematics, Management, University of Southampton, Highfield Southampton, SO17 1BJ, UK,
`p.beullens@soton.ac.uk`

A number of important models in the Operations Research literature that seek to minimise the future costs related to some activity include holding costs. While often referred to as inventory models, these models typically contain other important costs, such as set-up costs of production, order placement cost, and transportation costs. While any cost parameter is to be carefully specified in any practical context, it seems in particular quite hard to accurately quantify the inventory-related cost parameters (e.g. the unit holding cost and the unit backorder cost). One approach that has been applied with some success is the use of the Net Present Value (NPV), or the Annuity Stream (AS), see e.g. [1]. Next to quantifying the holding cost parameter values to be used in an inventory model, it is somewhat less known that this may also lead to the identification of: (1) significant yet forgotten terms in the objective function; (2) how the optimisation model is affected by the mode of operation in the supply chain (e.g. push or pull); (3) how other cost parameters can be more accurately specified from cash-flow structures, and (4) the degree of importance of the payment structures between the parties, see [2,3] . We demonstrate, using NPV Equivalence Analysis, the impact of aforementioned aspects on a few specific inventory-routing models, see also e.g. [4], in which one supplier delivers to a set of customers using vehicles of limited capacity in a vendor-managed inventory scenario. We analyse how different cash-flow arrangements and other choices related to parameter values affect characteristics of the solution such as average visit frequency, the profits of the firms involved, but also the indirect impact on social welfare related to transportation, see e.g. [5].

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The Distance Constrained Multiple Vehicle Traveling Purchaser Problem

Nicola Bianchessi*
Department of Economics and Management, University of Brescia, Italy, `bianche@eco.unibs.it`
Renata Mansini
Department of Information Engineering, University of Brescia, Italy, `rmansini@ing.unibs.it`
M. Grazia Speranza
Department of Economics and Management, University of Brescia, Italy, `speranza@eco.unibs.it`

In many business environment, as those involved in raw materials and components purchase, the selection of suppliers is a key procurement decision. Different aspects influence this decision and different contributions appeared in the literature where purchasing costs are optimized assuming that demand is either deterministic or stochastic. Nevertheless, procurement costs are not just determined by purchasing costs. Typically, transportation costs are a substantial component of procurement costs that needs to be optimized as well. A first procurement setting that explicitly incorporates both purchasing and transportation costs has been studied in [2].

In this work, we study a procurement setting where the purchaser company needs specified quantities of a variety of products from a set of suppliers and is involved in the direct collection of the purchased products with a fleet of vehicles based at a common depot. Each supplier offers a subset of products at possibly different prices and having different availabilities. The company has to select a set of suppliers and construct a set of routes so that total traveling and purchasing costs are minimized. A distance constraint is set on the route traveled by each vehicle. Such a constraint is determined by the working time of vehicle drivers. The problem generalizes the well-known Traveling Purchaser Problem (TPP) since a fleet, instead of a single vehicle, is available to visit suppliers. Due to the distance bound associated with each vehicle and the fleet of vehicles, we call this generalization the Distance Constrained Multiple Vehicle Traveling Purchaser Problem (DC-MVTPP). The DC-MVTPP is NP-hard, as, other than the TPP, it generalizes also the Distance Constrained VRP (DC-VRP). Indeed, any DC-VRP instance can be solved as an unrestricted DC-MVTPP instance where each supplier offers a product that is not available from the remaining ones, and all the products have to be purchased. To the best of our knowledge the problem has never been studied before. We define different mathematical formulations for the problem, including a three-index formulation using the Miller-Tucker-Zemlin generalization of subtour elimination constrains, a multi-commodity flow formulation and a set partitioning formulation. A branch-and-price algorithm is proposed for the solution of the set partitioning formulation. Variables representing feasible routes are dynamically generated. At each node of the search tree, while solving the LP relaxation of the problem, columns are priced out by means of a label setting algorithm addressing a Shortest Path Problem with Resource Constraints (SPPRC). Routes are imposed to be elementary at the set partitioning model level. An effective restricted master heuristic is used to prune the tree (see [1]). A set of instances has been derived from benchmark instances for the asymmetric TPP (see [3]). Instances with up to 100 suppliers and 200 products have been solved to optimality.

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A Destroy and Repair Search Heuristic for the School Bus Routing and Scheduling Problem with Transfers

Michael Bögl*
Johannes Kepler University Linz, Austria, `michael.boegl@jku.at`
Karl F. Doerner
Johannes Kepler University Linz, Austria, `karl.doerner@jku.at`
Sophie N. Parragh
University of Vienna, Austria, `sophie.parragh@univie.ac.at`

The school bus routing and scheduling problem deals with the transportation of pupils from home to school in the morning and from school to home in the evening. Variants of this problem are often studied in literature. A comprehensive overview of existing publications can be found in [2].

This work is motivated by a real life problem with about 1600 pupils, 235 bus stations and 22 schools, where the area of operation is mostly rural. We consider the so called morning problem only, i.e., the transportation of the pupils to their respective school before it begins. The goal is to generate an efficient transportation plan (according to some objective) so that every pupil arrives at school on time.

We consider multiple schools. Pupils of different schools can share a single bus and may change the bus during their way to school, referred to as transfers, which have not yet been extensively studied in the context of the school bus routing problem. Transfers in the context of transportation of goods are for example described in [1]. They use a pickup and delivery problem formulation with a predefined set of transfer points. In our case, every bus stop may be used as a transfer point and the decision which bus stops serve as transfer points is made by the optimization algorithm.

Literature distinguishes between the routing problem and the scheduling problem. School bus routes are calculated under consideration of pupil paths. Those routes are then scheduled to buses. Hence, a route is serviced by a single bus but a bus may serve multiple routes. In this work we handle both aspects of the problem.

First, we implemented a mixed integer linear program (milp) which integrates routing and scheduling under consideration of transfers. State of the art milp solvers are able to solve our formulation up to a few pupils and bus stops. To solve problem instances of the sizes of real world problems with hundreds of pupils and dozens of bus stops a heuristic approach is more promising.

Our heuristic solution concept is based on a destroy and repair search framework and uses exact methods for solving subproblems: At first a feasible set of bus and pupil routes is generated using a heuristic for a generalized minimum spanning tree with additional constraints for the given schools. Those routes are then scheduled by solving a simple temporal network.

The initial solution is then improved by iteratively applying destroy and repair operators. Parts of the routing solution are destroyed and then repaired under consideration of the bus scheduling. It may happen that for a given routing solution there exists no feasible scheduling solution. In those situations feedback loops are used where infeasibilities are stored and the routing solution is adapted according to the detected infeasibilities in the scheduling. Short term memory is used to prohibit cycling in the search.

At VeRoLog 2012 in Bologna we presented the overall problem description and the construction algorithm. This year we would like to focus on the iterative destroy and repair search method, the detection of infeasible solution parts and the feedback loop which are used to iteratively guide the search to a feasible solution.

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Route First Cluster Second-Based Formulations for a Variety of Routing Problems

Mouaouia Cherif Bouzid*
Department of Industrial Engineering and Maintenance, ENST, Rouiba, Algiers, Algeria.
USTHB-University, Faculty of Mathematics, Department of Operations Research,
LaROMaD-Laboratory, BP 32 El-Alia, Bab-Ezzouar 16111, Algiers, Algeria.,
`cherifmouaouia.bouzid@gmail.com`

Hacene Ait Haddadene
USTHB-University, Faculty of Mathematics, Department of Operations Research,
LaROMaD-Laboratory, BP 32 El-Alia, Bab-Ezzouar 16111, Algiers, Algeria.,
`aithaddadenehacene@yahoo.fr`

Said Salhi
Centre for Logistics & Heuristic Optimisation, Kent Business School, The University of Kent,
Canterbury, Kent CT2 7PE, UK., `s.salhi@kent.ac.uk`

In this talk, we observe that the partitioning of a giant tour for a multiple travelling salesman problem (mTSP) can be seen as a polynomially solvable 0-1 knapsack problem. Variations on this initial model permit to partition a giant tour for several types of routing problems. These include, among others, the mTSP with bounds on the number of cities to be visited (mTSP$_{[K,L]}$), the VRP, the heterogeneous VRP, the mTSP with time windows and the multidepot mTSP (MmTSP).

The routing first-cluster second approach has already been considered by Beasley [1], Golden et al [2] and more recently by Imran et al [3] using dynamic programming or network based methods. The latter consist in constructing a cost network then computing a shortest path to optimally partition the giant tour. Though the optimal partitioning can be performed in a polynomial time, generalising this method can be problematic even for small changes as fixing the number of vehicles to an integer m.

Partitioning an optimal giant tour will not always produce an optimal solution as there is a lack of correlation between the quality of the giant tour and the solution of its corresponding optimal partitioning.

In order to tackle this, we put forward a hybridisation of the variable neighbourhood search heuristic, introduced by Mladenović and Hansen [4], with our models. This approach consists in partitioning an initial giant tour then perturbing it and splitting again a number of times. Reiterating this process in association with a reoptimizer such as 2-opt or an exact method permits to improve the initial solution.

For empirical testing, we assess the performance of our split-based VNS heuristic using two variants namely the mTSP and the mTSP$_{[K,L]}$. Our hybrid approach performs well when compared to other approaches in litterature.

Computing times needed to solve the various models are presented. The CPU time needed to split a giant tour depends on the problem nature. In a VRP situation, a giant tour can be partitioned for instances of up to 261 cities and 6 vehicles. A cost network approach is however preferred for larger instances if m is free using Djikstra's algorithm or dynamic programming. On another hand, partitioning a giant tour for other variants such as the MmTSP can be performed quickly even for large instances. As an illustration only, the partitioning of a MmTSP 4460-nodes giant tour is performed within 2 seconds.

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A Set-Covering Based Heuristic for Rich Vehicle Routing Problems with a heterogeneous fleet

Felix Brandt*
FZI Forschungszentrum Informatik, Karlsruhe, Germany, `brandt@fzi.de`

Nitin Ahuja
PTV Group, Karlsruhe, Germany, `nitin.ahuja@ptvgroup.com`

Werner Heid
PTV Group, Karlsruhe, Germany, `werner.heid@ptvgroup.com`

Anne Meyer
FZI Forschungszentrum Informatik, Karlsruhe, Germany, `meyer@fzi.de`

Frank Radaschewski
PTV Group, Karlsruhe, Germany, `frank.radaschewski@ptvgroup.com`

The Heterogeneous Vehicle Routing Problem (HVRP), as defined by Golden et. al [1], assumes a fleet that is composed of different types of vehicles. Usually, the vehicles are differing in their loading capacities as well as fixed or variable costs. The objective is to minimize the total cost of all vehicles used in the solution. A recent review on promising approaches is given in [2].

One way to tackle the problem, presented by Taillard [3], is to solve a homogeneous fleet VRP for each vehicle type independently with an unlimited number of vehicles. Thereby, a lot of (partly overlapping) tours are generated. From these tours, the least cost subset visiting each customer once is found by solving a Set Partitioning Problem.

In our work, we apply and extend the ideas of Taillard, to enable a commercial library for rich but homogeneous fleet VRPs to handle heterogeneous fleets. For the creation of tour plans, we rely on the VRP software package PTV xTour Server. Thereby, we are able to incorporate all of its supported types of restrictions from real world problems, like break and rest rules or multi-trips. We propose different strategies to create a number of preferably diverse solutions from the homogeneous fleet VRPs. To finally find the least cost subset of tours, we choose a Set Covering formulation. To make each customer visited exactly once, we introduce one additional step to repair the solution. The main idea of this step is to generate promising subtours out of the tours that contain customers, which are visited more than once in the current solution. These subtours are added to the Set Covering problem, which is solved repeatedly until no more duplicate visits exist.

In this talk we present our solution approach, our insights of the experiment phase and from a real world application. Furthermore, we talk about some experience gained from implementing our approach into PTV xTour Server, a commercial vehicle routing solution.

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A Simple Parameter-Free Heuristic for the Fleet Size and Mix Problem with Time Windows

Olli Bräysy*
Faculty of Economics and Business Administration, VU University Amsterdam, De Boelelaan 1105, 1081 HV, Amsterdam, Netherlands., `olli.braysy@vu.nl`

Wout Dullaert
Faculty of Economics and Business Administration, VU University Amsterdam, De Boelelaan 1105, 1081 HV, Amsterdam, Netherlands
Institute of Transport and Maritime Management Antwerp, University of Antwerp, Kipdorp 59, 2000 Antwerp, Belgium, `wout.dullaert@vu.nl`

We suggest a novel metaheuristic for the fleet size and mix vehicle routing problem with time windows. Rather than using a gradual reduction of the threshold - common to traditional threshold accepting frameworks - our metaheuristic first sets the threshold value to zero to forbid worsening moves. The threshold is then reset to a randomly selected high value which is maintained for one iteration, during which established local search operators is applied to the current solution. For the next iteration, the threshold is again put to zero and the entire process is repeated for a preset number of iterations. Moreover, the search is strengthened by limiting the number of accepted moves that worsen the solution within an iteration. In doing so, we do not only increase the diversification offered by the threshold accepting mechanism, but also increase the number of effective local search moves that do modify the solution during the search. Computational testing on the 600 benchmark problems yielded over 300 new best-known solutions at lower average computational effort.

A LNS for the 2E-CVRP

Ulrich Breunig*
Production and Operations Management,
University of Vienna, Austria, `ulrich.breunig@univie.ac.at`

Verena Schmid
Production and Operations Management, University of Vienna, Austria; Centro para la Optimización y la Probabilidad Aplicada (COPA), Universidad de los Andes, Bogotá, Colombia,
`verena.schmid@univie.ac.at; v.schmid@uniandes.edu.co`

Richard F. Hartl
Production and Operations Management,
University of Vienna, Austria, `richard.hartl@univie.ac.at`

A local-search metaheuristic based on a Large Neighbourhood Search is developed and implemented to find good solutions within limited computing time for the Two-Echelon Capacitated Vehicle Routing Problem. Large trucks deliver goods from a depot to intermediate facilities, where freight is transferred to smaller vehicles, which then deliver it to customers. The goal is to satisfy all customer demands with the lowest possible costs and driven distance. For about half of the testinstances the current best known solutions are improved, within very reasonable computing times.

On One Class of Routing Optimization Problems

Efim Bronshtein*
Numerical Mathematics and Cybrtnetics Chair, Ufa State Aviation Technical University, Ufa, Russia,
`bro-efim@yandex.ru`

Ramiz Gindullin
Numerical Mathematics and Cybrtnetics Chair, Ufa State Aviation Technical University, Ufa, Russia,
`gramiz@mail.ru`

We consider the following situation. A vehicle should deliver a uniform cargo from some production points to some consumption points. The vehicle loaded (or unloaded) once at every point of production and consumption because the process of loading and unloading is very long. The vehicle moves by a closed route, its beginning and end point is the base (labeled 0). The weights $a_i (i = 0, ..., n)$ of cargo in the production points (in this case $a_i > 0$) or the need in the consumption points (in this case $a_i < 0$), the capacity of the vehicle S and the distance between all pairs of points are known. We assume that $\sum_{i=0}^{n} a_i = 0$.

Problem 1
Find S_{min} - minimum allowable capacity of the vehicle.
Problem 1 was reduced to the problem of linear Boolean programming by using a permutation matrix. Following estimates are valid.
Proposition

$$max\{|a_i|\} \leq S_{min} < 2 \cdot max\{|a_i|\},$$

estimates are correct.

Problem 2
Find the minimum length of a cycle, ensuring delivery of the cargo from the points of production to the points of consumption.
Two models are constructed:

- the boolean quadratic optimization problem;
- the integer linear optimization problem.

Three methods were applied for the exact solution of problem 2. The branch and bound method was used together with the linear and quadratic problems. Numerical experiment showed that the least laborious is the Boolean quadratic optimization.

The dependence was researched experimentally of minimal route length on the vehicle capacity. The minimum permissible capacity was defined as the solution of problem 1. We found that the average path length is almost stabilized at $S > 1,7 \cdot S_{min}$.

Some heuristic approaches to the solution of problem 2 were developed [1].

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Rich and Real-Life Vehicle Routing Problems: Cases of Study in Spain

José Cáceres Cruz*
Department of Computer Science, Multimedia, and Telecommunication. IN3-UOC, Barcelona, Spain.,
`jcaceresc@uoc.edu`

Daniel Riera, Angel Juan
Department of Computer Science, Multimedia, and Telecommunication. IN3-UOC, Barcelona, Spain.,
`drierat@uoc.edu, ajuanp@uoc.edu`

Helena R. Lourenço, Alex Grasas
Department of Economics and Business. Universitat Pompeu Fabra, Barcelona, Spain.,
`alex.grasas@upf.edu, helena.ramalhinho@upf.edu`

Roman Buil
Department of Telecommunications and Systems Engineering, UAB, Bellaterra, Spain.,
`roman.buil@uab.cat`

In the last few years, logistics and transportation companies are facing growingly demanding situations with fewer available resources due to market instability and the increasingly competitive business environment. Road haulage represents the main mode of goods transportation around the world. Since 2000, the economic and environmental impact caused by terrestrial transport has been growing. Governments and corporations have placed their attention on terrestrial logistics and the optimization of distribution processes. In academic literature, these problems are categorized as Vehicle Routing Problems (VRP), a popular research stream that has undergone significant theoretical advances but has remained far from practice implementations. Although some of these advances enable to solve real-world scenarios, there are still some critical assumptions made in the models that prevent their solutions from being applied in reality which are related to the emerging concept of Rich VRP [1]. The first attempts to define the Rich VRP (RVRP) have been made by [5] with the potential of extending models. Furthermore, [4] have proposed six integrative models considering some important extensions in the context of supply chain management. In fact, [3] refer to this type problem as an Industrial Routing Problem. The authors present a generic solver based on a unified algorithmic approach. A wide classification of the Rich VRP variants is presented in a special issue published by [2]. The editors state VRP research has often been criticized for being too focused on idealized models with non-realistic assumptions for practical applications. Finally [6] develops a study of several metaheuristics using classical variants of multi-attributes VRP. Generic approaches for Rich VRPs present a real challenge for research community. This study presents the current demand of enterprises for this type of development. We consider the problem features of three different distribution case studies in Spain.

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Facing the Parking Areas Problem for Dangerous Goods in the European Road Transport Network

Maria Dolores Caro[*]
Dept. Economics, Quantitative Methods, and Economic History, Pablo de Olavide University, Seville, Spain, `mdcarvel@upo.es`

Eugenio M. Fedriani
Dept. Economics, Quantitative Methods, and Economic History, Pablo de Olavide University, Seville, Spain, `efedmar@upo.es`

Ángel F. Tenorio
Dept. Economics, Quantitative Methods, and Economic History, Pablo de Olavide University, Seville, Spain, `aftenorio@upo.es`

Vehicles transporting dangerous goods require special conditions for parking. They must remain separated from other road users and be permanently supervised. Special security requirements must also be considered for this kind of transport when lorries are parked (see [1]). Moreover, European regulations about resting and driving time have to be strictly obeyed.

Related to this fact, several countries have already studied the following unsolved problem: how many parking areas are necessary to assure lorry drivers resting time in their respective national territories. Even more, where should they be placed?

The complexity of this initial problem lies in the high number of different routes and the existence of appropriated parking areas already settled. But the analysis of the situation in each country does not allow the obtention of an efficient solution (as in [2]). Hence, we propose a global approach, for the whole European transport road network, which would improve the overlapping of partial solutions.

Summarizing, we analyze national regulations and the current status of the network in each country. Then we find out a European-level solution by using Graph Theory (see [3]) and symbolic computation packages to implement adequate algorithms (some of them can be consulted in [4]), finally locating the minimal number of parking areas to satisfy the legal requirements in the European road transport network.

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The Multi Trip Vehicle Routing Problem with Time Windows and Release Dates

Diego Cattaruzza*
Department Sciences de la fabrication et logistique, Ecole des Mines de Saint-Etienne, CMP Georges Charpak, F. 13541 Gardanne, France, `cattaruzza@emse.fr`

Nabil Absi
Department Sciences de la fabrication et logistique, Ecole des Mines de Saint-Etienne, CMP Georges Charpak, F. 13541 Gardanne, France, `absi@emse.fr`

Dominique Feillet
Department Sciences de la fabrication et logistique, Ecole des Mines de Saint-Etienne, CMP Georges Charpak, F. 13541 Gardanne, France, `feillet@emse.fr`

In this paper, we introduce the Multi Trip Vehicle Routing Problem with Time Windows and Release Dates (MTVRPTWR) and propose a memetic algorithm for its heuristic solution.

This problem arises in the context of MODUM[1] project (founded by The French National Research Agency - ANR). In MODUM the development of an efficient system of mutualized distribution is studied. Carriers allowed to enter city centers (*vans* in the following) are parked at platforms located around the beltway where trucks *continuously* arrive during the day and are unloaded. Then, not all goods are available at the platforms at the beginning of the working day. This justifies the introduction of the concept of *release date* associated with the merchandise. Precisely, the release date represents the time merchandise is available at the platform for final delivery.

Final distribution to customers is made by vans with limited capacity, due to laws restriction imposed and the narrowness of streets that characterize historical parts of downtowns. Then, they are allowed to accomplish several trips during the working day. This introduces the multi trip aspect.

More formally, in the MTVRPTWR, a fleet of identical vehicles with limited capacity is based at the depot. A set of customer demands have to be fulfilled during the working day. The MTVRPTWR calls for the determination of a set of routes and an assignment of each route to a vehicle, such that the total routing cost is minimized and each customer is visited by exactly one route respecting capacity constraints on vehicles and time windows on customers. Moreover, each vehicle cannot leave the depot before the maximal release date associated with merchandise to be delivered in the trip vehicle is going to accomplish.

The MTVRPTWR is an extension of the Multi Trip VRP with Time Windows [1] that is in turn an extension of the Multi Trip VRP [2].

An adaptation of the Split procedure introduced by [3], in the VRP context, is used to evaluate chromosomes and obtain MTVRPTWR solutions from them.

A set of instances for the MTVRPTWR is introduced and the efficiency of the procedure is proved by result comparison on MTVRPTW instances with [1].

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Periodic Vehicle Routing Problem for Blood Distribution

Pornpimol Chaiwuttisak*
Mathematics , University of Southampton, Highfield, SO17 1BJ, `pc12g09@soton.ac.uk`

Honora Smith
Mathematics and Management, University of Southampton, Highfield, SO17 1BJ,
`Honora.Smith@soton.ac.uk`

Yue Wu
Management, University of Southampton, Highfield, SO17 1BJ, `Y.Wu@soton.ac.uk`

Regional Blood Centres (RBCs) have been established to collect blood from donors, prepare various blood products, test donated blood to ensure that blood without hepatitis, syphilis, and HIV and distribute safe blood to provincial hospitals. Currently, hospitals must collect blood using their own vehicles. As a consequence, it is difficult to manage logistics costs efficiently and control a quality standard of blood during transportation. In addition, hospitals' blood orders often exceed actual demands because supply is limited. As a result, amounts of blood supplied are reduced so that the supply to all hospitals is equitable. Planning regular schedules and routes is proposed to alleviate this situation. This research studies routes for blood services to hospitals in the Upper North region of Thailand, as a case study in a developing country. It forms part of a wider study of the supply chain process to fulfill hospital demands for fresh, quality blood supplies. An important consideration is transportation costs which have an effect on the total system costs in the network. The main objectives are to arrange a schedule for a one-week planning horizon and routes for blood delivery from the RBCs or the distribution centres to hospitals. We investigate two policies for blood distribution [1] : single visit frequency and multiple visit frequency for different hospitals.

For the first policy with one visit frequency for all hospitals, hospitals are clustered by geographical data into six groups for delivery on six days per week. Because the problem is NP-hard, heuristics and meta-heuristic methods are used to handle the large data set for this case study problem. Both Clarke and Wright (C&W) Single and Parallel Saving algorithms are compared as the solution methods to minimize the total distances. Then, local search is applied to improve the initial solutions. These are further compared with solutions obtained from the Greedy Randomized Adaptive Search Procedures (GRASP). It is found that GRASP can give a better solution than C&W on all clusters. The maximum number of vehicles needed for blood distribution with the same visit frequency is two. As a second policy, we assign differing frequencies of delivery to hospitals, according to hospital size and distance from the Regional Blood Centre. A fixed blood supply is assumed in this case. The problem thus contains the elements of schedule planning and routing, as in periodic vehicle routing problem [2]. The availability of blood supply is based on historical data. Hospitals that are close together are allocated to the same route in each day. Each hospital receives blood by the proportion of its blood usage to the total blood supply subject to meeting the required visit frequency. This policy requires a greater total distance travelled than the first policy, but it can meet customer satisfaction in an improved manner.

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Branch-Cut-and-Price for the Pickup and Delivery Problem with Time Windows and LIFO Loading

Marilène Cherkesly*
GERAD, Département de mathématiques et génie industriel, École Polytechnique de Montréal, Canada,
`marilene.cherkesly@gerad.ca`

Guy Desaulniers
GERAD, Département de mathématiques et génie industriel, École Polytechnique de Montréal, Canada,
`guy.desaulniers@gerad.ca`

Gilbert Laporte
Canada Research Chair in Distribution Management, HEC Montréal, Canada,
`gilbert.laporte@cirrelt.ca`

In this presentation, we focus on the pickup and delivery problem with time windows and last-in-first-out (LIFO) loading (PDPTWL). LIFO loading ensures that no handling is required while unloading objects from the vehicle: a linear stack loading structure is assured and an object can only be delivered if it is the one closest to the door. To solve this problem, we propose three exact branch-cut-and-price algorithms. The first algorithm incorporates the LIFO constraints in the master problem. The second algorithm handles the LIFO constraints directly in the shortest path subproblem. To solve it, a dynamic programming algorithm relying on an ad hoc dominance criterion is developed. The third algorithm is a hybrid between the first two methods. We adapt known valid inequalities to the PDPTWL and study the impact of different path relaxations on the total computation time. Computational results will be presented.

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An Optimized Target Level Inventory Replenishment Policy for Vendor-Managed Inventory Systems

Leandro C. Coelho*
CIRRELT and Faculté des sciences de l'administration, Université Laval, Québec, Canada G1K 7P4,
`leandro.coelho@cirrelt.ca`

Gilbert Laporte
CIRRELT and HEC Montréal, 3000 chemin de la Côte-Sainte-Catherine, Montréal, Canada H3T 2A7,
`gilbert.laporte@cirrelt.ca`

In Vendor-Managed Inventory (VMI) systems, the supplier is responsible not only for delivering the products and routing its vehicles to serve its customers, but also for determining when and how much to deliver to them. The combined optimization of inventory control and vehicle routing gives rise to the Inventory-Routing Problem (IRP). There exist several real-life applications of this problem. The survey paper of [1] concentrates on the applications of the IRP whereas [2] provide an overview more focused on the methodological aspects of the problem.

In the IRP literature, two inventory replenishment policies are traditionally used. The first one, called maximum level (ML), gives full flexibility to the supplier. The quantity delivered to a customer only has to comply with its inventory capacity. The other policy, which is much more constrained, is called order-up-to (OU). Under an OU policy, whenever a customer is visited, its inventory level is brought up to its maximum capacity. The OU policy simplifies the solution process since it effectively removes one decision dimension from the problem. Indeed, whenever a customer is visited, the quantity delivered is automatically computed as the difference between the inventory capacity and the current inventory level.

While the implementation of an OU policy simplifies the supplier's decision process and can increase customer satisfaction, it is not without disadvantages since it leads to cost increases which can be as high as 20% over an ML policy [3,4]. An interesting question is therefore whether one can determine an optimal consistent replenishment level for each customer without incurring the full cost of an OU policy. As the authors are aware, the determination of a system-optimal and customer-dependent stable replenishment level has never been investigated in a VMI context.

Our objective is therefore to propose a new tactical replenishment policy that would combine the customer-related advantages of OU and the supplier-related benefit of ML which affords more flexibility and lower system costs. This new policy, which we call *optimized target level* (OTL), determines an optimal replenishment target level for each customer. It can be viewed as an optimized OU policy, except that instead replenishing up to the customer's capacity, the supplier fills the customer's inventory up to an OTL. In order to take advantage of this new idea, the OTL of each customer is computed simultaneously with the remaining routing and inventory decisions, in order to jointly optimize the inventory holding costs and the routing costs. We show that it yields lower costs and inventory levels than the OU policy, and is only marginally more expensive than the ML policy, while being easier to implement.

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A Branch-and-Cut Algorithm for the Close-Enough Directed Arc Routing Problem

Ángel Corberán*
Departament dEstadística i Investigació Operativa, Universitat de València, Spain.,
`angel.corberan@uv.es`

Thais Ávila
Departament dEstadística i Investigació Operativa, Universitat de València, Spain.,
`thais.avila@uv.es`

Isaac Plana
Departamento de Matemáticas para la Economía y la Empresa, Universitat de València, Spain.,
`isaac.plana@uv.es`

José Mara Sanchis
Departamento de Matemática Aplicada, Universidad Politécnica de Valéncia, Spain.,
`jmsanchis@mat.upv.es`

The Close-Enough Directed Arc Routing Problem (CEDARP) is an arc routing problem with additional constraints from the Set Covering Problem (SCP), which has an interesting real-life application in the design of routes for meter reading (see [2]). It is a generalization of the Directed Rural Postman Problem where the set of arcs on which we must "do the service" is not defined a priori. Instead, there is a set of customers to be served. Customers can be located in the area covered by the graph, not only at the vertices and arcs of the graph. The CEDARP consists of finding a minimum cost tour starting and ending at the depot, satisfying that each customer is "served" by the tour, that is, the customer is "close enough to an arc traversed by the tour. This problem has been studied in Ha et al. [3]. In that paper several formulations are compared and a branch-and-cut procedure obtaining very good computational results is proposed. The CEDARP is also related to the Generalized Directed Rural Postman Problem studied by Drexl [1]. In this work, we first propose an integer programming formulation of the problem similar to one already presented in [3]. Then, we define and study the polyhedron associated with its feasible solutions and, finally, a branch-and-cut algorithm for its exact resolution is proposed. Computational results on a large set of instances are presented.

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Constrained Dynamic Vehicle Routing Problem with Time Windows

Jesica de Armas*
*Dpto. de Estadística, I.O. y Computacíon, Escuela Técnica Superior de Ingeniería Informática,
Universidad de La Laguna, 38271, La Laguna, Spain.*, `jdearmas@ull.es`

Belén Melián-Batista
*Dpto. de Estadística, I.O. y Computacíon, Escuela Técnica Superior de Ingeniería Informática,
Universidad de La Laguna, 38271, La Laguna, Spain.*, `mbmelian@ull.es`

José A. Moreno-Pérez
*Dpto. de Estadística, I.O. y Computacíon, Escuela Técnica Superior de Ingeniería Informática,
Universidad de La Laguna, 38271, La Laguna, Spain.*, `jamoreno@ull.es`

A Constrained Dynamic Vehicle Routing Problem with Time Windows has been tackled as a real-world application, where customer requests can be either known at the beginning of the planning horizon or dynamically revealed over the day. Companies offering these services often have a heterogeneous fleet of vehicles. Moreover, in our real-world problem, customers and vehicles can have more than one time window in the same planning horizon. In addition, customers can be postponed according to their assigned priorities. There also exist constraints that do not allow certain customers to be visited by some of the vehicles due to road restrictions. Extra hours for the vehicles may also be allowed in our problem, which incur in additional costs. Finally, several objective functions are considered and hierarchically evaluated: total traveled distance, time balance, that is defined as the longest minus the shortest route in time required, and cost, which includes fuel consumption and other salaries.

Using exact methods is not a suitable solution for this kind of problems, since the arrival of a new request has to be followed by a quick re-optimization phase to include it into the solution at hand. Therefore, we have proposed a metaheuristic procedure to solve this particular problem. First of all, an initial solution consisting of all the static customers is generated by using the Solomon Heuristic [2]. The obtained solution is then improved running a Variable Neighborhood Search (VNS) algorithm proposed in [1] to solve the static problem with all the constraints above. This process is iterated for a certain number of iterations and the best reached solution is selected to be implemented by the company. At this phase, all the requests known at the beginning of the planning horizon are already inserted in a route.

Once the selected initial solution is being implemented, new dynamic customers might be revealed over the planning horizon. The algorithm first tries to insert a new customer in the closest possible feasible existing route. From the last visited customer to the last customer in the route, it is searched the feasible insertion point either with the least distance increment. If the previous option is not feasible and no feasible alternative is available for the new customer, then a new route is created with the new customer and the VNS algorithm is applied in order to obtain a better solution, only if there is a free suitable vehicle. In other case, there are two options. On one hand, in case that extra hours are allowed for the vehicles, violating their time window constraints, the new customer is tried to be inserted in a route. On the other hand, if extra hours are not permitted by the company, then the notion of request priority shows up. If the new customer has a low priority, then it can be postponed until the following day. If it is not possible, but there is another routed customer that can be postponed allowing the insertion of the new one, then the routed customer is postponed, while the new one is inserted. If all the previous attempts have failed, the new customer is inserted in the route with the least increment of infeasibility.

The computational experiments indicate that the proposed method is both feasible to solve this real-world problem and competitive with the literature.

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A Fast and Exact Routing Engine for Large Dynamic Road Networks

Daniel Delling*
Microsoft Research Silicon Valley, USA, `daniel.delling@microsoft.com`

Thomas Pajor
Karlsruhe Institute of Technology, Germany, `pajor@kit.edu`

Andrew Goldberg
Microsoft Research Silicon Valley, USA, `goldberg@microsoft.com`

Renato Werneck
Microsoft Research Silicon Valley, USA, `renatow@microsoft.com`

We present customizable route planning (CRP [1]), a routing engine to compute exact shortest paths in continental road networks (with tens of millions of road segments). The engine is able to incorporate realistic turn costs, custom height and weight restrictions, personal preferences, and traffic in real time. Moreover, it can efficiently answer extended queries such as computing distance tables or best points-of-interest, which are important building blocks of advanced logistics applications.

The basic idea of CRP is to divide the work into three phases. The preprocessing phase uses only the topology of the road network as input and computes some auxilliary data [1,2]. Since the topology does not change very often, this phase is allowed to run in up to an hour (small updates to the topology are faster). The second phase, called customization, takes as input the graph, the actual cost function (e.g., travel time), and the output of the first phase. It computes a moderate amount of additional data, and runs in less than one second [3]. The third phase then uses the graph and the output of both preceding phases to answer exact shortest path queries in real time. The supported query scenarios are point-to-point shortest paths, distance tables, and best points-of interest. As a result, for most logistics applications, the routing engine is no longer the bottleneck, as our live demo will show.

Some of the CRP technology is currently used by Bing Maps [4].

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Environmental Impacts of Intermodal Freight Transportation

Emrah Demir*
School of Industrial Engineering, Eindhoven University of Technology, 5600MB Eindhoven, The Netherlands, `e.demir@tue.nl`

Tom Van Woensel
School of Industrial Engineering, Eindhoven University of Technology, 5600MB Eindhoven, The Netherlands, `t.v.woensel@tue.nl`

Transportation activities require increasing mobility demands for freight. A well-organized freight transportation system is essential for economic development. However, it is obvious that it also causes serious problems in form of negative impacts on environment and human health. The negative impacts of transport are in general associated with costs. These costs are usually denoted as 'external costs' or 'externalities'. Externalities are in general paid by society in contrast to internal costs, such as costs for fuel, driver wages, etc., which are paid by the logistics provider and thus ultimately by their customers.

Until last decade, the planning of freight transportation activities has mainly focused on ways to save money or to increase profitability by considering internal transportation costs only. With an ever growing concern for the environment by governments and other private entities worldwide, companies have started taking externalities of logistics into account. Such factors should be taken into account in the design of logistics activities, so as to yield environmental benefits. The externalities include pollution, accidents, noise, resource consumption, land use deterioration, and climate change risk.

An intermodal freight transportation involves the transportation of freight in an intermodal container or vehicle, using multiple modes of transportation, without any handling of the freight itself when changing modes [1]. The intermodal freight transportation is much more complicated than a mono-modal transportation but offers more opportunity to reduce the environmental impacts of freight transportation by scheduling the services and routing the freight [2]. In order to reduce externalities in freight transportation, there is a need of better understanding and modeling the intermodal service system.

In this study, we propose a mathematical programming approach in the form of a linear cost, multi-commodity, capacitated network design formulation that minimizes the externalities of transportation activities. The formulation used to measure externalities is based on a comprehensive consideration of the state-of-the-art tools of relevance to externalities. Computational results are presented on realistic instances to show the performance of the proposed approach.

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Oil Platform Transport Problem (OPTP)

Ocotlán Díaz-Parra*
Center of IT, Universidad Autónoma del Carmen, Mexico., `ocotlan@diazparra.net`

Jorge A. Ruiz-Vanoye
Center of IT, Universidad Autónoma del Carmen, Mexico.,

María de los Ángeles Buenabad Arias
Center of IT, Universidad Autónoma del Carmen, Mexico.,

The Oil Platform Transport Problem consist of to minimize the cost of carry resources, goods or people from one location (airport/platform) to another location (airport/platform) using helicopters with some restrictions as capacity and time windows. The Oil Platform Transport Problem is considered as a combination/interlink of the two well-studied NP-Hard/NP-Complete problems: the Helicopter Routing Problem-HRP (a generalization of the Split Delivery Vehicle Routing Problem) and the Bin Packing Problem - BPP. We provide the proof that this problem is NP-Hard/NP-Complete Problem by the polynomial transformation using formal languages between the Split Delivery Vehicle Routing Problem and the Oil Platform Transport Problem.

We propose a new mathematical model to the Oil Platform Transport problem, and we present the parameters or characterization of Oil Platform Transport Problem instances of Mexican state-owned petroleum company (PEMEX). We generated 5 instance set, each instance set has 25 cases of randomly generated instances and real instances (with GIS data) of PEMEX Oil Platforms. PEMEX is the biggest company of Mexico and Latin America, and the most important fiscal contributor of the Mexico. It is of the few oil companies of the world that develops all the productive chain of the industry, from the exploration, to the distribution and commercialization of all the products. PEMEX has a total asset worth of $415.75 billion, and is the world's second largest non-publicly listed company by total market value, and Latin America's second largest enterprise by annual revenue, surpassed only by Petrobras (a Brazilian petrochemical company).

We use the CPLEX solver to find the optimal cost of carry resources, goods or people contains in the Oil Platform Transport Problem.

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A Meta-heuristic Algorithm for a Split Delivery Vehicle Routing Problem with Clustered Backhauls

Massimo Di Francesco*
Department of Mathematics and Computer Science, University of Cagliari, Italy, `mdifrance@unica.it`
Michela Lai
School of Mathematics and Computer Science, University of Cagliari, Italy, `mlai@unica.it`
Maria Battarra
Mathematics, University of Southampton, Highfield Southampton, SO17 1BJ,
`M.Battarra@soton.ac.uk`

This research addresses a rich Vehicle Routing Problem (VRP), motivated by a container distribution application. Our carrier is based at a port in the North of Italy and is responsible for the delivery of full containers from the port to import customers, and the collection of full containers from export customers to the same port. In order to preserve containers' and loads' integrity, truck drivers participate to all loading and unloading operations. Full containers are emptied and collected at the importers; empty containers are filled in the presence of the driver at the exporters. In addition, since exporters are typically not ready for collection before the afternoon, importers are visited before exporters. Finally, importers and exporters may ask for the delivery and collection of a number of containers larger than the truck capacity, therefore more than a truck frequently visits the same customer. Split of the load is therefore allowed, even when not necessary. The objective consists of defining a set of routes in which routing costs are minimized, all customers are serviced (importers before exporters), and the trucks' capacity is never exceeded. The proposed problem is called hereafter Split Delivery Vehicle Routing Problem with Clustered Backhauls (SD-VRPCB). We present an Integer Linear Programming formulation, capable of solving small-sized instances, a constructive heuristic and a meta-heuristic, based on Adaptive Guidance mechanisms.

The constructive heuristic first decomposes the SD-VRPCB into two subproblems: the Split Delivery VRP (SDVRP) considering only importers, and the SDVRP considering only exporters. These two problems are separately solved using the Tabu Search (TS) by Archetti et al. [1]. The routes consisting of importers or exporter customers are merged by an ILP model based on the saving concept.

The solution obtained by the constructive heuristic is analyzed with respect to four performance measures and, if drawbacks are identified, Adaptive Guidance mechanisms penalize suitable input parameters of the TS. The penalizations guide the TS toward the construction of routes that can be effectively matched by the ILP model. We present preliminary results obtained on a large set of benchmark instances, comparing the meta-heuristic solutions with the optimal solutions of small-sized instances and with the solutions of the constructive heuristic.

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The Hybrid Electric Vehicle Traveling Salesman Problem

Christian Doppstadt*
Detlef-Huebner-Chair of Business Administration, Logistics and Supply Chain Management, Goethe University, Frankfurt am Main, Germany, `doppstadt@wiwi.uni-frankfurt.de`

The reduction of carbon dioxide and other exhaust gas is one of the major challenges of our society. A huge emphasis achieving this is set on motor vehicles, especially, passenger cars. Nevertheless, in many concerns electric vehicles (EVs) are not yet competitive. A main disadvantage here is the limited range due to the restricted battery capacity and its energy density, compared to conventional internal combustion engines (ICEs). One way to overcome this, is the usage of hybrid electric vehicles (HEVs), which combine an electric and a combustion engine [1]. For passenger cars this development has reached mass production, whereas, small transporters and trucks have not left the state of prototypes yet [2]. However, the potential of reducing exhausts of transporters seems high as the operational profile, in particular for end customer deliveries matches scenarios with possible savings: within urban areas, short distances can be covered using the electric engine only and distances to or between different delivery areas can be used to recharge the battery. For an overview on HEVs we refer to [3].

We introduce a new optimization problem covering exactly these types of scenarios. The Hybrid Electric Vehicle Traveling Salesman Problem (HEVTSP) considers the delivery or–without loss of generality– the pick up of goods at a set of customer locations with a HEV from a depot. The HEVTSP is an extension of the well known and widely studied Traveling Salesman Problem (TSP) [4,5]. in accordance with the prototype presented in [2] our model uses four different modes of operation: mere combustion, mere electric, charging while driving with combustion engine and combined combustion electric. The modes differ in costs and travel time for all arcs within a complete graph. This makes the problem very difficult to solve, as it increases the number of possible solutions for the NP-hard TSP by a factor of 4^n, with n as number of nodes within the graph. From the scientific point of view the HEVTSP is highly relevant, as it on one hand covers a critical problem within the courier express parcel (CEP) industry and on the other hand–to our knowledge–has not been investigated so far.

Beside the problem formulation, we provide benchmark instances based on real world delivery areas and performance measures, gained from GPS-data of actual tours by a large parcel delivery company. Our model is able to support decision makers in terms of investment decisions for HEVs, the profit of using Plug-in HEVs, break even analysis on prices for fuel and batteries, forecasts on the change of tour durations, etc. Finally, we solve small instances of the problem with CPLEX and determine bounds for the larger instances.

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On the Generalized Directed Rural Postman Problem

Michael Drexl*
Chair of Logistics Management, Gutenberg School of Management and Economics, Johannes Gutenberg University, Mainz, Germany, and Fraunhofer Centre for Applied Research on Supply Chain Services SCS, Nuremberg, Germany., `drexl@uni-mainz.de`

The generalized directed rural postman problem (GDRPP) is a generic type of arc routing problem. In the talk, it is described how many types of practically relevant single-vehicle routing problems can be modelled as GDRPPs. This demonstrates the versatility of the GDRPP and its importance as a unified model for postman problems. In addition, a heuristic solution approach, based on a transformation into the generalized asymmetric travelling salesman problem (GATSP), is presented. Computational experiments using a state-of-the-art heuristic for the GATSP (developed by [1]) are performed, using a large set of realistic instances. The results show excellent solution quality in short computation time and thus demonstrate the practical usefulness of the transformations.

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Vehicle Routing with Vendor Selection, Intermediate Pickups and Deliveries

Uğur Emec*
Sabanci University, Faculty of Engineering and Natural Sciences, Istanbul, 34956 Turkey,
`uguremec@sabanciuniv.edu`

Bülent Çatay
Sabanci University, Faculty of Engineering and Natural Sciences, Istanbul, 34956 Turkey,
`catay@sabanciuniv.edu`

Burçin Bozkaya
Sabanci University, Sabanci School of Management, Istanbul, 34956 Turkey,
`bbozkaya@sabanciuniv.edu`

Shopping habits of consumers have rapidly changed in the last decade as a result of new developments in e-commerce, with many more consumers who prefer online shopping. Thus, leading online retailers look for new strategies to diversify their in-stock standard products with outsourced premium products, i.e. products with a higher profit potential, to satisfy and increase diverse consumer demand in a collaborative relationship with external vendors. In this setting, consumer demand for premium products is fulfilled either directly by external vendors or by online retailers with fulfillment centers for external vendors to store their products. Two main motivations of our study are: (1) to develop an alternative model for this collaborative relationship by considering additional business rules; and (2) to construct an efficient solution procedure to enable more online retailers to take advantage of this promising business strategy.

In our proposed model, premium product orders are fulfilled directly from online retailers without requiring external vendors to use fulfillment centers. For this purpose, our model is built on a distribution network consisting of (1) a depot or store of an online retailer that only supplies standard products, (2) vendors, i.e. external stores that only supply their individual premium products, (3) regular customers, i.e. customers that only purchase standard products, and (4) premium customers, i.e. customers that additionally purchase premium products. To solve this problem in a VRP setting, two decisions are made simultaneously: the assignment of vendor(s) to each premium customer to satisfy premium product order and the routing of all customers along with their respective vendors while honoring feasibility in terms of vehicle capacity and time windows. We refer to this problem as VRP with Vendor Selection, Intermediate Pickups and Deliveries (VRPVSIPD). To the best of our knowledge, a similar model is only suggested by [1].

In order to solve VRPVSIPD, we develop a mathematical model, which minimizes total transportation cost. We attempt to solve it on new data sets prepared for VRPVSIPD by modifying Solomon VRPTW instances via CPLEX 12.2 library with a Java interface. CPLEX is unable to produce feasible solutions even for 25-node instances in an acceptable time period. So we propose an improved Adaptive Large Neighborhood Search (ALNS) heuristic framework with a simulated annealing local search procedure. This framework combines the strengths of the ALNS heuristics previously put forward by [2] and [3] by modifying some existing removal-insertion procedures as well as introducing novel removal-insertion and vendor selection-allocation procedures specific to VRPVSIPD. We first benchmark our algorithm against well-known VRPTW instances of Solomon and find strikingly good results when compared to those in [2] and [3]. We then report the solutions we find for the Solomon instances modified for VRPVSIPD. Finally, we present a GIS-integrated case study with real data in the city of Istanbul, Turkey.

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Fleet Deployment and Speed Optimization in RoRo Shipping

Kjetil Fagerholt*
Industrial Economics and Technology Management, Norwegian University of Science and Technology, Trondheim, Norway, `kjetil.fagerholt@iot.ntnu.no`

Henrik Andersson
Industrial Economics and Technology Management, Norwegian University of Science and Technology, Trondheim, Norway, `henrik.andersson@iot.ntnu.no`

Kirsti Hobbesland
Industrial Economics and Technology Management, Norwegian University of Science and Technology, Trondheim, Norway,

We consider a fleet deployment problem for a ship operator in the roll on-roll off (RoRo) segment of liner shipping dealing with the transportation of cars, trucks and other types of rolling material. Fleet deployment is a tactical decision with a planning horizon of typically 3 - 9 months. Given a heterogeneous fleet of ships and a number of voyages that the company must service, the problem is to assign a ship to each voyage in order to minimize the cost. We present a mathematical formulation for this planning problem that considers frequency requirements for voyages and demand between different geographical areas. We also treat sailing speeds of the ships on the individual voyages and the ballast sailing legs as decisions variables, where the non-linear relation between speed and fuel consumption is approximated with a piecewise linear function.

To solve problems of real size, a rolling horizon heuristic is proposed. The principle of the heuristic is to solve the problem iteratively through the planning horizon. The planning horizon is partitioned into time periods, which each consist of two sections. The first section is the central section and the second is the forecasting section. During a given iteration, the planning problem for that time period is solved. The solution in the central section is then frozen and a new planning problem for the following time period is defined. In the new problem, the forecasting section of the previous iteration becomes the new central section. The algorithm continues until the solution for the whole planning horizon is frozen.

The method has been tested on real data provided by a shipping company. The largest instances have more than 50 ships and 300 voyages, covering a 9 month planning horizon. The tests show that the proposed method performs well and produces good solutions. The results also show that significantly better solutions are obtained when incorporating speed as decision variables in the fleet deployment planning.

A Genetic Algorithm Approach to Solve the Team Orienteering Problem — Comparing Different Solution Strategies

João A. O. Ferreira[*]
Centre ALGORITMI, University of Minho, Portugal, `joao.aoferreira@gmail.com`

José A. Oliveira
Centre ALGORITMI, University of Minho, Portugal, `zan@dps.uminho.pt`

Luís S. Dias
Centre ALGORITMI, University of Minho, Portugal, `lsd@dps.uminho.pt`

Guilherme A. B. Pereira
Centre ALGORITMI, University of Minho, Portugal, `gui@dps.uminho.pt`

Introduction: Currently, commercially available software to assist in the management of the selective waste collection process do not usually meet the optimal standards of efficiency, effectiveness and cost control. Therefore, new tools and methodologies are needed in order to help real life managers deal with resource and budgetary requirements, while respecting constraints imposed on them. The main issue associated with the selective waste collection procedure is fleet management, since vehicles are used to pick-up the waste in different collection points, each one with an associated priority level. This translates perfectly to the standards of a Vehicle Routing Problem (VRP). In fact, the problem can be modelled as a Team Orienteering Problem (TOP). In the TOP, a vehicle fleet is assigned to visit a set of customers of known demand, while executing optimized routes that maximize total profit and minimize resources needed, which will result in the selection of customers to be served. Likewise, waste collection problem often leads to the selection of collection points that need to be visited, so the TOP models are best suited for this case.

Objectives: The objective of this work is to optimize the waste collection process while addressing the specific issues around fleet-management. We intend to apply the principles of the TOP to the selective waste collection procedure, and also evaluate two software tools previously developed to solve the TOP. We aim to achieve challenging results in comparison to previous work around this subject of study. Methods: The developed software tools (GATOP-1 and GATOP-2) implement two methods based on genetic algorithms. They differ mainly in the chromosome construction procedure, fitness selection rules and the genetic operations used.

Results: The proposed task of solving the TOP was accomplished. Our computational tests have produced some challenging results. Specifically, GATOP-1 achieved a success rate of 91.37% while comparing to the best known results in a selection of 24 benchmark instances. With GATOP-2, the success rate was 96.53%. The test results are compared with the ones presented in [1] and [2]. The best solutions found with GATOP-1 took from 3 two 9 minutes to be calculated. As for GATOP-2, it only needed from just a few seconds to 4 minutes at most to output its best results. GATOP-2 proved to be more efficient than GATOP-1 by being more accurate and faster in the tests performed.

Conclusions: The developed software (GATOP-1 and GATOP-2) can be used as auxiliary tools in the management of the waste collection procedure, when modelling it as a TOP. The use of genetic algorithms proved to be an efficient method by outputting good results in an acceptable time, which in real-world situations is able to improve fleet management in the waste collection procedure by optimizing the collection routes in a small amount of time and in a more accurate way than most currently applied methods.

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Planning of Home Health Care Transport Services with Subroutes and Interdependencies

Christian Fikar[*]
Institute of Production and Logistics, University of Natural Resources and Life Sciences, Vienna, Austria, `christian.fikar@boku.ac.at`

Patrick Hirsch
Institute of Production and Logistics, University of Natural Resources and Life Sciences, Vienna, Austria, `patrick.hirsch@boku.ac.at`

Urbanization and an ageing population cause various challenges for home health care (HHC) providers [3]. Among these are congestion, limited parking spaces, a rise in the number of nurses without driver's permits and a drastic increase in demand for HHC services. While public transport is often utilized in urban areas [4], alternative concepts are required to provide a high quality of service in suburban settings where public transport operates less frequently. Currently, nurses primarily operate separate vehicles which is costly and results in high emissions. We present a model formulation and solution approach for the daily planning of HHC providers, which operate a fleet of vehicles that deliver and pickup nurses to and from clients' homes. Hereby, the objective criterion is to minimize the total working time over all nurses. The nurses' scheduled visits are not predetermined, but decided within the model. With its implementation, HHC providers are able to reduce the total number of vehicles and operate more sustainably, while nurses do not loose valuable time searching for parking spaces. In cooperation with our partner, the Austrian Red Cross, one of the main providers of HHC services in Austria, and based on previous work [5], various requirements are considered such as maximum ride times, assignment constraints, working time regulations and mandatory breaks. Additionally, subroutes, e.g. the possibility to walk to the next client instead of using the transport service, and delivery dependent pickup time windows are taken into account. In contrast to [2], subroutes can end at any job. The impact of synchronization and interdependencies on vehicle routing problems is extensively discussed by [1]. Our introduced solution approach consists of two stages, identifying potential subroutes of nurses and routing of the vehicles. Based on a maximum walking duration between two jobs, a complete set of all feasible subroutes and multiple initial sets containing each job exactly once are constructed in the first stage. In the second stage, parallel programming and multi-start techniques are used to diversify the solution space by enabling different sets of subroutes and flexibility in pickup and delivery points. Two Tabu Search based solution approaches are used in the optimization. The solution approaches are tested with real life data of two Austrian cities. Moreover, a comparison to the currently used concept [5] where each nurse operates a separate vehicle is provided. This should lead to more efficient and environmentally friendlier solutions in order to facilitate sustainable transport in the context of home health care.

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Two Approximation Methods for Bi-Objective Combinatorial Optimization: Application to the TSP with Profits

Carlo Filippi*
Department of Economics and Management, University of Brescia, Italy, `filippi@eco.unibs.it`

Elisa Stevanato
Department of Economics and Management, University of Brescia, Italy,
`elisa.stevanato@eco.unibs.it`

We describe two approximation methods for bi-objective combinatorial optimization problems with nonnegative, integer valued objectives. The procedures compute a representative set of the efficient points such that any other efficient point is within an arbitrary factor from a computed one with respect to both objectives. Both methods are simple modifications of classical algorithms for the construction of the whole efficient set, where a properly defined single objective subproblem has to be solved at every iteration. In both cases, the number of subproblems to be solved and the number of returned efficient points are polynomial in the input size and the reciprocal of the allowed error. Moreover, a fast post-processing guarantees that the number of returned efficient points is at most three times the minimum possible number needed to approximate the efficient set within the specified tolerance.

We test the procedures on the Traveling Salesman Problem with Profits, where profits and costs are treated as conflicting objectives. Here, the single objective subproblems are variants of the TSP, and are solved by standard branch-and-cut techniques. Results are taken on randomly generated instances and on TSPLIB instances. We show that both methods return a guaranteed approximation with significant time sparing with respect to exact procedures. We also give empirical evidence that in the specific application the number of points returned by the approximation methods is much smaller than the upper bound and close to the minimum.

The Time-Dependent Pollution-Routing Problem

Anna Franceschetti*
School of Industrial Engineering, Eindhoven University of Technology, Eindhoven, The Netherlands 5600MB, `A.Franceschetti@tue.nl`

Dorothée Honhon, Tom Van Woensel
School of Industrial Engineering, Eindhoven University of Technology, Eindhoven, The Netherlands 5600MB, {`D.B.L.P.Honhon, T.v.Woensel`}`@tue.nl`

Tolga Bektaş
Southampton Management School and Centre for Operational Research, Management Science and Information Systems (CORMSIS), University of Southampton, Southampton, United Kingdom SO17 1BJ, `T.Bektas@soton.ac.uk`

Gilbert Laporte
Canada Research Chair in Distribution Management, HEC Montréal, Montréal, Canada H3T 2A7, `Gilbert.Laporte@cirrelt.ca`

The Time-Dependent Pollution-Routing Problem consists of routing a fleet of vehicles in order to serve a set of customers and determining the speeds on each leg of the routes. The cost function comprises of fuel, emissions and driver costs, taking into account traffic congestion which, at peak periods, significantly restricts vehicle speeds and increases emissions. In this paper, we make use of time-dependent travel times and model traffic congestion using a two-level speed function as in [1]. We assume there is an initial period of congestion followed by a period of free-flow. This modeling framework is suitable for routing problems which must be executed in the first half of a given day, e.g., starting from a peak-morning period where traffic congestion is expected, and following which it will dissipate. To calculate vehicle emissions, we use the *comprehensive emissions model* of [2] which includes factors as load an speed. We describe an integer linear programming formulation of the TDPRP and provide illustrative examples to motivate the problem and give insights about the tradeoffs it involves. We also provide an analytical characterization of the optimal solutions based on a single-arc version of the problem, identifying conditions under which it is optimal to wait idly at certain locations in order to avoid congestion and to reduce the cost of emissions. Building on these analytical results we describe a departure time and speed optimization algorithm on a fixed route. Finally, using benchmark instances, we present results on the computational performance of the proposed formulation and on the speed optimization procedure.

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Neighborhood Search Approaches for a Vehicle Routing Problem with Multiple Trips and Driver Shifts

Véronique François*
HEC - Management School of the University of Liège, Belgium, `veronique.francois@ulg.ac.be`
Yasemin Arda
HEC - Management School of the University of Liège, Belgium, `yasemin.arda@ulg.ac.be`
Yves Crama
HEC - Management School of the University of Liège, Belgium, `yves.crama@ulg.ac.be`

In this study, we analyze a rich vehicle routing problem, whose features are inspired from the practical case of a Belgian distribution company. We consider a distributor who has to satisfy the demand of two types of customers: the delivery and backhaul customers. In a given route, backhaul customers can only be visited after all delivery customers of the route are served. Multiple trips [3] are allowed and the different trips of a given vehicle are said to form a tour. There is a single commodity that is shipped from a single depot. Split deliveries and pick-ups are not allowed. A time window and a service time is associated with each customer.

The distributor owns a fleet of vehicles with heterogeneous capacities and equipment. The problem considers site-vehicle dependencies. Each vehicle can be used during a given period related to the shift of its driver. The usual shift duration can be exceeded but this implies an overtime cost. The distributor can also hire additional vehicles with homogeneous capacities, which are supposed to be available at any required time for a given maximal duration.

The objective function includes a distance cost for both fleets, a fixed cost for the use of external vehicles, and a time cost which depends on the considered fleet type. In the case of the external fleet, the time cost depends on the complete tour duration (traveling time, waiting time, and service time). In contrast, only an overtime cost is incurred for internal vehicles.

The combination of multiple trips, driver shifts, and external vehicles whose tours have to be scheduled with minimum duration makes the problem particularly challenging. To the best of our knowledge, these features have not been simultaneously considered in the literature.

Two metaheuristics were implemented to solve the considered problem: an adaptive large neighborhood search (ALNS) [2] and a variable neighborhood search (VNS) [1]. For the shaking phase of the VNS, embedded neighborhoods are obtained by combining a removal heuristic with an insertion heuristic of the ALNS and by increasing the number of removed customers. Consequently, the main difference between the two metaheuristics is the local search phase present in the VNS but not in the ALNS.

In both metaheuristics, specific multi-trip versions of well-known operators have been built to allow the creation of new routes or the splitting of existing ones during the insertion process. Moreover, route merging procedures are used in order to reduce the number of routes in a vehicle tour if necessary.

In the ongoing numerical tests, a particular attention is paid to the contribution of different heuristics and neighborhood combinations to the quality of the solutions.

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Exact and Heuristic Solutions of the Carrier-Vehicle Travelling Salesman Problem

Claudio Gambella*
DEI "Guglielmo Marconi" University of Bologna, Italy, `claudio.gambella@unibo.it`
Andrea Lodi
DEI "Guglielmo Marconi" University of Bologna, Italy, `andrea.lodi@unibo.it`
Daniele Vigo
DEI "Guglielmo Marconi" University of Bologna, Italy, `daniele.vigo@unibo.it`

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 limitated 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 (CV-TSP) 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. 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].

We present a new exact formulation for CV-TSP that is also used as a starting point for the heuristic solution of this problem.

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A Contraction-Expansion Algorithm for the Capacitated Minimum Cost Flow Problem

Jean-Bertrand Gauthier[*]
HEC Montréal, Canada, `jean-bertrand.gauthier@hec.ca`

Jacques Desrosiers
HEC Montréal, Canada, `jacques.desrosiers@hec.ca`

Marco E. Lübbecke
RWTH Aachen University, Germany, `marco.luebbecke@rwth-aachen.de`

Inspired by recent advances in coping with degeneracy in the primal simplex method, we show that a slight modification of the *Improved Primal Simplex* (IPS) used for solving degenerate linear programs [1,2] results in a strongly polynomial algorithm for solving capacitated minimum cost network flow problems. Given network G containing n nodes and m arcs, the new algorithm is similar to the well known minimum mean cycle-canceling algorithm [3,4] that performs $O(m^2n)$ iterations.

The algorithm works as follows. Given a set of node potentials, improving reduced cost cycles during a phase are found on a *contracted residual network*, where each connected component made of free arcs is shrunk to a single node. Solving a minimum mean reduced cost cycle problem on the contracted residual network yields a strictly improving direction.

We take the time to analyze the behavior of the algorithm through key concepts of the complexity analysis. In particular, a phase comprises at most $O(m)$ expansions (iterations) at the start of which a contraction is performed. Each expansion observes the aftermath of the improving cycle, as such arcs that become free are expanded. Results for the assignment and the shortest path problems will also be presented.

Acceleration strategies used in the implementation are discussed and involve the concepts established in IPS such as compatibility and independent cycles. Moreover, we bias the algorithm around the residual capacities and the reduced cost of previous iterations to speed up the search.

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A Comparison of Different Column-Generation Formulations for the Pickup-and-Delivery Problem with Static and Dynamic Time Windows

Timo Gschwind*
Chair of Logistics Management, Gutenberg School of Management and Economics, Johannes Gutenberg University Mainz, Mainz, Germany, `gschwind@uni-mainz.de`

The Pickup-and-Delivery Problem with Static and Dynamic Time Windows (PDPSDTW) is a Vehicle Routing Problem (VRP) with pairing and precedence, capacities, and static and dynamic time windows. Thereby, a static (or ordinary) time window restricts the point of time a specific customer can be serviced. A dynamic time window, on the other hand, couples the service times at two customer nodes in the following way: A delivery node has to be serviced within a given minimum and maximum time spread after the service at the corresponding pickup node has been completed. The PDPSDTW, thus, is the prototypical VRP with temporal intra-route synchronzation constraints generalizing the Pickup-and-Delivery Problem with Time Windows (PDPTW) where no dynamic time windows are present and the Dial-a-Ride Problem where only a maximum time spread is specified.

Many successful solution approaches for VRP variants rely on integer column generation using formulations that include all the constraints relating to single routes in the subproblem. These formulations have the advantage of tighter lower bounds compared to formulations where some route constraints are handled in the master problem. The overall success of an integer column-generation approach for VRPs, however, relies not only on strong bounds but also on the effective solution of the subproblem. Thus, it is a priori not clear if the integration of all route constraints into the subproblem pays off, especially if there are groups of constraints that are hard to handle in the subproblem.

Subproblems of VRP variants are typically Elementary Shortest Path Problems (ESPP) with resource constraints that are solved using labeling algorithms. The strength of such a labeling algorithm can mainly be attributed to the use of strong dominance rules. While the ESPP with pairing and precedence, capacities, and static time windows has been well studied in the context of the PDPTW and effective labeling algorithms exist for its solution ([1,2]) the additional presence of dynamic time windows severely complicate the problem. Recently, [3] proposed labeling algorithms for the special case where only a maximum time spread is specified. By means of a simple example, we can show that a straightforward extension of their approach to also include minimum time spreads, however, is not possible.

Our contribution is twofold: First, we devise a new dominance rule that is valid for the ESPP with pairing and precedence, capacities, and static and dynamic time windows. For the first time both static and dynamic time windows (with minimum and maximum time spread) can be fully handled by an effective label setting algorithm. This allows for an integer column-generation algorithm for the PDPSDTW where all route constraints are handled in the subproblem.

Second, we compare this algorithm to approaches based on alternative forumlations in a computational study. These formulations use subproblems relaxing either the maximum or minimum time spreads, or both and, hence, can be solved using labeling algorithms with stronger dominance rules. Preliminary results, however, indicate that the additional effort in the subproblem pays off in the overall algorithm.

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Kernel Search for Capacitated Facility Location Problems

Gianfranco Guastaroba*
Department of Economics and Management, University of Brescia, Brescia (Italy), C.da Santa Chiara 50, `guastaro@eco.unibs.it`

M. Grazia Speranza
Department of Economics and Management, University of Brescia, Brescia (Italy), C.da Santa Chiara 50, `speranza@eco.unibs.it`

Capacitated facility location problems are among the most investigated problems by the OR community. The related literature can be divided into two classes: papers dealing with the Single Source Capacitated Facility Location Problem (SSCFLP) and those tackling its Multi Source (MSCFLP) version. In the SSCFLP each customer has to be assigned to one facility that supplies its whole demand. On the other hand, in the MSCFLP each customer demand can be supplied by one or more facilities. In both versions, the total demand of customers supplied by each facility cannot exceed its capacity. An opening cost is associated with each facility and is paid if at least one customer is supplied from it. The objective is to minimize the total cost of opening the facilities and supply all the customers. Both problems are NP-hard.

In this talk we present a Kernel Search algorithm for solving capacitated facility location problems. The Kernel Search is a heuristic framework based on the idea of intensively exploring a sequence of relatively small/moderate-size portions of the solution space instead of searching the solution domain as a whole. The exploration is guided by the identification of subsets of decision variables and the subsequent solution to optimality of the resulting restricted problems by means of a general-purpose LP/MILP solver used as a black-box. The subsets of decision variables are constructed starting from the optimal values of the linear relaxation. The framework is quite flexible and it proved its effectiveness for other MILP and BILP problems. In this talk, the general Kernel Search framework is successfully applied to the solution of capacitated facility location problems. Variants of the general framework based on variable fixing are proposed aiming at improving the efficiency of the algorithm. The heuristics are tested on a very large set of benchmark instances and the computational results confirm the effectiveness of the approach. The optimal solution has been found for almost all the instances whose optimal solution is known. Most of the best known solutions have been improved for those instances whose optimal solution is still unknown. Computational times are reasonable given the size of the instances solved.

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A Lower Bound for the Point-to-Point Quickest Path Problem

Emanuela Guerriero[*]
Department of Engineering, Università del Salento Via Monteroni 73100 Lecce, Italy,
`veronique.francois@ulg.ac.be`

Gianpaolo Ghiani
Department of Engineering, Universià del Salento Via Monteroni 73100 Lecce, Italy,
`gianpaolo.ghiani@unisalento.it`

The fast computation of point-to-point fastest paths on very large time-dependent road networks will allow next-generation web-based travel information services to take into account both congestion patterns and real-time traffic information. In a typical application setting, where a web server needs to answer several quickest path queries in a fraction of a second on graphs with millions of nodes, state-of-the-art algorithms are still too slow or require impractical off-line preprocessing times. One of the key ingredients of speed-up techniques is the computation of lower bounds on the time to the target. In this paper we illustrate a new lower bound for the point-to-point Time-Dependent Fastest Path Problem (TD-FPP). The TD-FPP can be defined as follows. Let $G = (V; A)$ be a graph, where V is a node set and A is an arc set. With each arch $(i; j) \in A$ is associated a function $\tau_{ij}(t)$ representing the time a vehicle, leaving at time t, takes to traverse the arc. Given a start time t and a path $p = (s = v_1, v_2, ..., v_k = d)$ from an origin $s \in V$ to a destination $d \in V$, its *traversal time* $z_p(t)$ is defined recursively as $z_{(v_1,...,v_i)}(t) = z_{(v_1,...,v_{i-1})}(t) + \tau_{(v_{i-1},v_i)}(t + z_{(v_1,...,v_{i-1})}(t))$, with the initialization $z_{(v1,v2)}(t) = \tau_{(v1,v2)}(t)$.

The TD-FPP aims at determining a path $p = (s = v_1, v_2, ..., v_k = d)$ such that $z_p(t)$ is minimum. As reasonable in practical applications [1], we assume the arc travel time functions are piecewise linear and satisfy the FIFO property (i.e., if a vehicle leaves s at time t it will arrive in d no later than a vehicle v_0 leaving s at time $t_0 > t$.

The TD-FPP could be solved in principle by a trivial modification of the Dijkstra's classical algorithm. However, for continental-sized graphs with millions of nodes this approach would take several seconds on a typical workstation. Hence, several speed-up techniques (Core-ALT, SHARC, etc) have been developed during the last four years [1]. One of the key ingredients of such techniques is the computation of lower bounds on the time to the target. In this talk, we present a new lower bound that has been embedded into an A* algorithm [2]. Computational results show that the algorithm outperforms the procedures described in the literature.

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Supply of Liquid Petroleum Gas to Fuel Stations — An Example of Carrier Managed Inventory Replenishment

Pawel Hanczar*
Department of Logistics, Wroclaw University of Economics, ul. Komandorska 118/120, 52-345
Wroclaw, Poland, `pawel.hanczar@uw.wroc.pl`

This paper presents a study conducted in a company distributing LPG from the storage plant to fuel stations throughout the territory of Poland. The examined company, one of few on the Polish market, implements modern service execution including not only transport support but planning and scheduling of deliveries. In business practices, this process is referred to as Vendor Managed Inventory; however the described goal of the company in question is to ensure the availability of LPG to fuel stations with the lowest cost of transportation. Both bottling infrastructure alongside the fuel stations belong to the largest Polish distributors of fuels.

In the first part of the paper, the areas of distribution, infrastructure and the characteristics of the fuel supply to stations are presented. The second part contains a description of the scheme of supply planning, scheduling procedures, as well as a list of the basic problems that arise during planning and delivery. In the final part, the first version of the optimization algorithm is proposed, the use of which will reduce the operational time required and reduce supply costs.

The main research objective presented in this paper is the determination of the procedures and practices used in fuel distribution companies, to identify the main elements of the planning process, as well as an initial indication of the possibility of applying the discussed methods of optimization. This paper presents the first variant of the optimization algorithm, which will be expanded so that it maps the entire supply planning process. Location-based heuristics were selected, which, due to there versatility, will cover most of the required extensions.

Solving Routing Problems with the GPU

Geir Hasle*
SINTEF ICT, Dept. of Applied Mathematics, Oslo, Norway, `geir.hasle@sintef.no`
Torkel Haufmann
SINTEF ICT, Dept. of Applied Mathematics, Oslo, Norway, `torkel.haufmann@sintef.no`
Christian Schulz
SINTEF ICT, Dept. of Applied Mathematics, Oslo, Norway, `christian.schulz@sintef.no`

Due to physical limits, hardware development no longer results in higher speed for sequential algorithms, but rather in increased parallelism. Modern commodity PCs include a multi-core CPU and at least one GPU, providing a low cost, easily accessible heterogeneous environment for high performance computing. New solution methods that combine task parallelization and stream processing and self-adapt to the hardware at hand are needed to fully exploit modern computer architectures and profit from future hardware developments. In this talk, we give an introduction to modern PC architectures and the GPU [1], and survey the literature on GPU-based solution methods in discrete optimization [2] that currently consists of some 100 papers. Many of them describe GPU implementations of well-known metaheuristics and report impressive speedups relative to a sequential version [3]. As for applications and problems studied, 26 papers describe research on routing problems of which 9 focus on the Shortest Path Problem, 15 discuss the Travelling Salesman Problem, and only 2 study the Vehicle Routing Problem. Finally, we describe a GPU-based Travelling Salesman Problem solver and present numerical results for large-scale instances.

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The Electric Fleet Size and Mix Vehicle Routing Problem with Time Windows

Gerhard Hiermann[*]
Austrian Institute of Technology, Austria, `Gerhard.Hiermann.fl@ait.ac.at`
Jakob Puchinger
Austrian Institute of Technology, Austria, `Jakob.Puchinger@ait.ac.at`
Richard F. Hartl
University of Vienna, Austria, `Richard.Hartl@univie.ac.at`

With the increase of public programs to encourage the use of electric vehicles and the shift of social reception towards so called energy efficient solutions the research in the field of vehicle routing using low-emission vehicles has increased as well. We therefore introduce a new problem, the so-called *Electric Fleet Size and Mix Vehicle Routing Problem with Time Windows* (EFSMVRPTW). The problem covers real world applications where an optimal mix of different available battery powered (and conventional) vehicles has to be found.

The EFSMVRPTW can be seen as a generalization of two other VRPs: On the one hand, the *Electric Vehicle Routing Problem with Time Windows* (EVRPTW) introduced by Schneider et al. [1], where the goal is to find optimal tours from a single depot to customers using a homogeneous fleet under consideration of a distance dependent energy resource, which can be replenished in optional recharging stations. On the other hand, the *Fleet Size and Mix Vehicle Routing Problem with Time Windows* (FSMVRPTW) introduced by Liu and Shen [2], where a heterogeneous fleet of different vehicles (with different load capacities and acquisition costs) has to be used to serve all customers, minimizing not only the distance and waiting time, but also the acquisition cost of the vehicles used.

In the EFSMVRPTW we search for the optimal mix of different electric vehicle types minimizing the overall distance and acquisition costs while satisfying time window and energy resource constraints. As in the EVRPTW we can use a set of intermediate facilities to recharge the vehicles, implying a recharge time relative to the distance travelled since the last recharging station or the depot.

In this work we generate a new benchmark set based on the existing FSMVRPTW and EVRPTW instances, which are both modifications of the well known Solomon instances with 100 customers, 21 recharge stations and three to six vehicle types. Additionally, we generated a set of smaller instances (with 5 to 15 customers).

We propose a mixed integer programming model for the problem and are able to solve some of the smaller instances using CPLEX. Furthermore we implemented a heuristic approch based on the ALNS framework described by Pisinger and Ropke [3] and use it to solve the EFSMVRPTW instances. In addition we tested our approach on the EVRPTW and FSMVRPTW instances in order to compare it with the state-of-the-art methods for those problems.

Preliminary computational results on the smaller instances as well as the comparison with existing methods for similar problems show that good quality solutions for the EFSMVRPTW can be expected.

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Efficient Local Search for the CARP with Combined Exponential and Classical Neighborhoods

Stefan Irnich*
Chair of Logistics Management, Gutenberg School of Management and Economics, Johannes Gutenberg University Mainz, Mainz, Germany, `irnich@uni-mainz.de`

The capacitated arc-routing problem (CARP) is the prototypical constrained arc-routing problem with applications in waste collection, mail distribution, snow plowing, and salt/sand gritting etc. Real world instances often comprise very large street networks so that heuristics require very fast algorithmic components. This paper focuses on the key building blocks of any local search-based procedure and presents new and efficiently searchable neighborhoods. More precisely, the contribution is twofold: First, we introduce several new inter-tour neighborhoods that combine classical edge-exchange moves such as 2-opt*, swap, and Or-opt (known from the VRP) with exponential TSP neighborhoods that allow edge flipping [1] and edge permutations according to Balas-Simonetti neighborhood [2]. The new neighborhoods are clearly exponential in the problem size n (proportional to number of required edges). Second, we show that these neighborhoods can however be searched in quadratic time $O(n^2)$ in the worst case. Compared to [1], the neighborhoods are larger and at the same time the computational effort for exactly searching a first/best improving neighbor is lower. Moreover, we use the sequential-search concept [3] to further reduce the computational effort so that these neighborhoods remain very attractive even if very large-scale problem instances with a few hundreds of required edges need to be solved. We will present an in-depth analysis comparing the computation effort among neighborhoods and search techniques.

CARP solutions are represented by a giant tour in which only depot nodes and required edges are present. Required edges are modeled by their two endpoints so that two consecutive nodes in the giant tour alternately model a service and a deadheading along a shortest path. We exemplify the general approach by considering the well-known 2-opt* move that takes two routes, determines a cut position in each route, and exchanges the resulting end segments between the routes. If the two routes are $r_1 = (s_1, e_1)$ and $r_2 = (s_2, e_2)$ with start segments s_1, s_2 and end segments e_1, e_2, the new routes are (s_1, e_2) and (s_2, e_1). Muyldermans et al. [1] already considered the possibility that within the move the edge orientations of the required edges in s_1, s_2, e_1, and e_2 may change so that the resulting new routes are flip-optimal, i.e., no change in edge orientation produces a better solution. The extension of the Balas-Simonetti neighborhood considered in [4] combines edge flipping with edge permutations. A best 2-opt* move in the newly proposed neighborhood is one that determines the two routes, the two cut positions, and the overall best flipping and permutation of all edges in s_1, s_2, e_1, and e_2. Finally, the sequential search version [3] of the search procedure uses the well-known gain criterion [5] in order to prematurely stop the search if no improving solution can result. Note that however sequential search guarantees that a first/best improving neighbor is found whenever one exists.

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A Heuristic Approach to the Urban Transit Routing Problem

Matthew John*
School of Computer Science & Informatics, Cardiff University, Cardiff, United Kingdom,
`JohnMP@cardiff.ac.uk`

The Urban Transit Routing Problem (UTRP) is of major significance in public transport planning. It involves the determination of a set of routes (for example buses, trains or trams) exploiting an existing transport network meeting the demands of passengers, whilst balancing the cost to the operator. The UTRP contains a diverse range of complexities that in turn make the problem difficult to solve using traditional optimisation methods such as exact algorithms. Construction heuristics have become popular for generating solutions that can then be used to seed a meta-heuristic algorithm. A new heuristic approach has been established that incorporates the underlying transport network and demand between transit stop pairs. The effect of seeding an evolutionary algorithm with heuristic and random solutions was then analysed, resulting in an improvement in the Pareto optimal set when utilising heuristic solutions.

Horizontal Cooperation in Multi-Vehicle Routing Problems with Environmental Criteria

Angel A. Juan*
Department of Computing Science - Open University of Catalonia, Barcelona, Spain, `ajuanp@uoc.edu`

Javier Faulin
Department of Statistics and OR - Public University of Navarre, Pamplona, Spain,
`javier.faulin@unavarra.es`

Elena Pérez-Bernabeu
Department of Applied Statistics and OR, and Quality - Technical University of Valencia, Alcoy, Spain,
`elenapb@eio.upv.es`

This paper presents the use of horizontal cooperation in road transportation solving a multivehicle routing problem and supports the relevance of this praxis as a way of reducing distribution costs and CO2 emissions. The object of logistic management is to optimise the whole value chain of the distribution of goods and merchandise. There are many procedures to solve the vehicle routing problems (VRP) associated to problems of road transportation. This paper examines different scenarios in order to quantify the savings in route costs that can be attained throughout horizontal cooperation considering at the same time environmental criteria. The problem of having good estimations of environmental costs has many facets depending on the particular transportation aspect to be considered: CO2 emissions, particles emanations, noise production, pollution of green areas, and contamination of urban districts, among others. Our method is based on a set of well-known benchmarks for the multi-depot vehicle routing problem, which is used as a paradigm of horizontal cooperation. Moreover, we want to manage costs using environmental estimations of pollutants emissions based on surveys about road transportation crossing rural areas with a valuable environmental stock. An iterated local search algorithm is proposed to obtain high-quality solutions for this collaborative scenario, while non-collaborative scenarios are solved using a well-tested algorithm for the capacitated vehicle routing problem. We analyze environmental impacts in both scenarios making interesting comparisons between the total delivery costs in road transportation with and without those environmental costs. These considerations raise the value of the global objective function, permitting a realistic analysis of the importance of horizontal cooperation in the control of the environmental impact of road transportation. Finally, this methodology is illustrated with the results of a case study.

Parking Reservations in Shared Mobility Systems

Mor Kaspi*
Department of Industrial Engineering, Tel-Aviv University, Israel, `morkaspi@post.tau.ac.il`
Tal Raviv
Department of Industrial Engineering, Tel-Aviv University, Israel, `talraviv@eng.tau.ac.il`
Michal Tzur
Department of Industrial Engineering, Tel-Aviv University, Israel, `tzur@eng.tau.ac.il`

Shared mobility systems are increasingly deployed in cities around the world. Such systems allow users to rent a vehicle (either a car or a bicycle) for a short period and return it in any of the system's stations scattered throughout the city. There are many advantages to shared mobility systems. Among others, they reduce city traffic congestion and improve utilization of city land resources, as the need for parking spaces is decreased. Financially, the sharing of resources results in lower costs per user compared to owning a private vehicle. In addition, users are not troubled about securing the vehicle when not in use and are not troubled about repairs.

The main challenge of shared mobility system operators is to satisfy demands for vehicles (on rent) and for vacant parking spaces (on return). The demands are typically stochastic, non-stationary and asymmetric processes. Occasionally, users may find that some stations are empty (no available vehicles) and some are full (no available parking spaces). In this study we measure the performance of the system by the total excess time spent by users due to unfulfilled requests for vehicles or parking spaces.

For the first time, we propose using reservation policies in shared-mobility systems and examine their effect. In particular, we focus on reservations of the parking spaces. In this study we investigate a policy which we refer to as the Complete-Parking-Reservation (CPR) policy. According to this policy, when a user rents a vehicle he declares his destination station and a vacant parking space in that station is reserved for him, if one is available. This assures that when the user reaches his destination he will be able to return his vehicle. If there is no available parking at the destination the transaction is denied and the user can either abandon the system or try to reserve a parking space in a different station.

The CPR policy is compared to the base policy, entitled No-Reservation (NR). We prove that if the demand rate is not too high, the CPR policy always performs better than the NR policy. Furthermore, we demonstrate analytically that the CPR policy outperforms the NR policy whenever the capacity of the system, relative to workload, is large enough to provide adequate service level. This claim is also verified via extensive simulation study of large realistic systems.

A Hybrid Algorithm for the Split Delivery Vehicle Routing Problem

Alexey Khmelev*
Novosibirsk State University, Russia, `avhmel@gmail.com`

Yuri Kochetov
Sobolev Intitute of Mathematics, Russia, `jkochet@math.nsc.ru`

In this work we study the Split Delivery Vehicle Routing problem (SDVRP), a variant of the VRP in which multiple visits to customers are allowed. For this NP-hard problem we design a hybrid heuristic. It is based on local search ideas and uses sequences of customers for coding solutions. We apply two decoding procedures with linear and quadratic complexity for the sequences. One of the procedures is a greedy algorithm, which can split demands. Another procedure uses dynamic programming method. Our hybrid algorithm applies the well-known variable neighborhood descent approach (VND) and uses the randomized tabu search procedure (RTS) for diversification. There are three types of neighborhood structures in our VND approach. In the first type of neighborhoods we change the sequences by swap, shift, and 2-opt moves. In the second type we change the solutions by creating or removing some splits. In the third type we use two ejection chain procedures. RTS uses only greedy decoding procedure and randomized 2-opt neighborhood. It helps to change the region of the solution space. For accelerating each iteration we ignore the moves, which generate the long travels between customers.

The problem sets of Archetti et al. [1] and Chen et al. [2] is used in computational experiments. This hybrid algorithm is evaluated and compared with the memetic algorithm with population management of Boudia et al. [3], tabu search with vocabulary building approach of Aleman et al. [4] and hybrid algorithm (EMIP+VRTR) of Chen et al. [2]. Computational experiments indicate that the proposed algorithm is very competitive. It improves 21 best-known solutions in the 70 test instances with number of customers up to 280.

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Construction Heuristic for a Vehicle Routing Problem with Time-Dependent Functions

Alexander Kleff*
Logistics Optimisation Components, PTV Group, Haid-und-Neu-Str. 15, 76131 Karlsruhe, Germany,
`alexander.kleff@ptvgroup.com`

Vehicle routing problems have lots of diverse applications. This leads to numerous different planning attributes, constraints and optimisation goals in practice. Equally high is the number of algorithmic approaches. But an algorithm which addresses many real-world scenarios must be flexible and cannot rely on specialities some use cases might have while others don't. In contrast to project-specific solutions, a multipurpose software product is in need of such a general algorithm. Here, the literature is comparatively scarce.

Some of the problems that arise in practice and that we would like to address with the same approach comprise multiple time windows per customer, soft time windows, alternative pickup resp. delivery points (e.g., multiple depots), multiple routes per vehicle, an inhomogenous fleet, and vehicles that need to start from and return to their home locations which may differ from the depot locations.

We are going to outline a new construction heuristic. As such, it is to find a good initial solution quickly on which usually some improving metaheuristic sets up. The main advantages of our approach are twofold: Firstly, its underlying model is flexible enough to cope with the input data of several different use cases which we indicated above. Secondly, it works with time-dependent functions which enables us to better optimise for time issues in general.

In the most general variant of our algorithm, its input contains two sets of time-dependent functions for every pair of customers: a driving and a stopover function set. Each function maps some point in time to a vector of values: one dimension is reserved for a duration (driving time or stopover time), the others can be used for modelling purposes. We expect functions to be piecewiese-linear throughout. Furthermore, every duration function is assumed to satisfy the FIFO property.

The algorithm itself is based on two ingredients. One is to iteratively merge two routes (resp. chains of routes) much like in the savings heuristic by Clarke and Wright. The other is a time-dependent shortest-path subroutine to compute these merges.

We are going to present the algorithm and its underlying model in more detail. We will also talk about how to derive a time-dependent stopover function from usually given input data (e.g., time windows) and how its flexibility can be used to cover diverse real-world cases. We have recently started implementing our ideas and hope to be able to show some preliminary results.

An Evolutionary Algorithm for the Heterogeneous Fleet Pollution-Routing Problem

Çağrı Koç*
Southampton Management School and CORMSIS, University of Southampton, Southampton, Highfield SO17 1BJ, United Kingdom, c.koc@soton.ac.uk

Tolga Bektaş
Southampton Management School and CORMSIS, University of Southampton, Southampton, Highfield SO17 1BJ, United Kingdom, t.bektas@soton.ac.uk

Ola Jabali
Department of Logistics and Operations Management, HEC Montréal 3000, chemin de la Côte-Sainte-Catherine, Montréal, Canada H3T 2A7, ola.jabali@hec.ca

Gilbert Laporte
Canada Research Chair in Distribution Management, HEC Montréal 3000, chemin de la Côte-Sainte-Catherine, Montréal, Canada H3T 2A7, gilbert.laporte@cirrelt.ca

This paper presents a hybrid genetic algorithm for the Heterogeneous Fleet Pollution-Routing Problem (HFPRP). The Pollution-Routing Problem (PRP) is a recently introduced extension of the classical Vehicle Routing Problem with time windows, consisting of routing vehicles to serve a set of customers, and determining their speed on each route segment to minimize a function comprising fuel, emission and driver costs [1]. The HFPRP is a new variant of the PRP, extending it to consider a heterogeneous vehicle fleet.

The proposed algorithm is based on hybrid genetic search with adaptive diversity control described and successfully used in [2], which combines the exploration mechanisms of population-based evolutionary search with the improvement capabilities of local search using advanced population-diversity management schemes. The local search is used to "educate" individual solutions within the populations of solutions evolved within the algorithm. The education phase uses Adaptive Large Neighborhood Search (ALNS) as the local search heuristic [3] and is based on the idea of gradually improving a starting solution by using both destroy and repair operators. The ALNS is shown to provide good results for the PRP [4]. Within the algorithm, an adapted version of the Speed Optimization Procedure (SOP) [5] is applied on each candidate solution. The SOP evaluates the cost for each type of vehicle for each tour to choose the least-cost option, and optimizes the speed on each segment of the route in order to minimize an objective function compromising fuel consumption costs and driver wages.

This talk will describe the components of the algorithm in detail and present results on its performance using the PRP library instances which are available at http://www.apollo.management.soton.ac.uk/prplib.htm.

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Optimization of Service Start Time for an Elementary Shortest Path Problem

Hande Küçükaydın*
HEC Management School, University of Liège, Liège, Belgium, `hkucukaydin@ulg.ac.be`
Yasemin Arda
HEC Management School, University of Liège, Liège, Belgium, `yasemin.arda@ulg.ac.be`
Yves Crama
HEC Management School, University of Liège, Liège, Belgium, `yves.crama@ulg.ac.be`

We are concerned with an elementary shortest path problem with resource constraints (ESPPRC), where there is a capacitated single vehicle at the depot for serving a set of delivery and backhaul customers with a time window. On a given route, the vehicle can visit a backhaul customer only after all its delivery customers are visited, where the delivery and backhaul customers are considered to be two disjoint sets. Split deliveries and pick-ups are not allowed. In this problem, the vehicle may be assigned to several routes. In addition, the vehicle can begin servicing the customers at any desired time and can be used for at most a fixed amount of time that depends on the shift duration of the assigned driver. Distance and time based variable costs are incurred by serving the customers. Namely, the total cost depends on the total distance traveled and the total amount of time that the vehicle spends by performing the assigned multiple trips. On the other hand, serving a customer yields also a revenue. Therefore, the objective is to determine the optimal service start time of the vehicle from the depot along with the trips to be performed in order to minimize the total of the distance and time costs minus the collected revenues. Such a problem can be faced as the pricing subproblem in branch-and-price algorithms for vehicle routing problems with additional constraints, where the revenues are equivalent to the dual prizes of the visited vertices.

In general, ESPPRC can be solved to optimality by using a dynamic programming algorithm. However, since the vehicle can start the service at any point in time and is paid based on the total time during which it has been used, our ESPPRC has to take an infinite number of Pareto-optimal states into account. Therefore, we adapt the well-known dynamic programming algorithm according to this feature and develop piecewise linear time functions that represent total traveling and waiting time depending on a variable start time at the depot. Consequently, we propose appropriate dominance rules to discard feasible paths that cannot lead to the optimal solution. Finally, computational results are presented.

An Exact Algorithm for the Robust Stochastic Inventory Routing Problem with Outsourced Transportation

Demetrio Laganà[*]
Department of Mechanical, Energy and Management Engineering,University of Calabria, Italy,
`demetrio.lagana@unical.it`

Luca Bertazzi
Department of Economics and Management, University of Brescia, Italy,
`bertazzi@eco.unibs.it`

Adamo Bosco
ITACA S.r.l., Arcavacata di Rende (CS), Italy,
`bosco@itacatech.it`

We study the *Inventory Routing Problem with Outsourced Transportation* from the stochastic and robust optimization point of views. Such a problem models the situation in which one supplier has to make decisions on when and how much to deliver to a set of retailers over a finite and discrete time horizon. The supplier has a limited production capacity at each time period and the demands of the retailers are either defined on the basis of a probability distribution (stochastic case) or unknown (robust case), while the deliveries are performed by using an outsourced fleet of vehicles. The goal consists in minimizing either the expected total cost (stochastic case) or the total cost in the worst case (robust case), represented by the sum of different cost components: 1) the total inventory cost at the supplier, 2) the total inventory cost at the retailers, 3) the total penalty cost arising whenever a stock-out occurs at the retailers, and 4) the total outsourced transportation cost to serve the retailers. We assume that the size of all deliveries is defined in accordance to the *Order-up-to Level* (OU) policy, in which the quantity delivered to each retailer fulfills the storage capacity. This situation arises, for example, when inventory decisions related to a set of retailers occur in a VMI system where small package deliveries, fulfilling the capacity requirements, are frequently needed over a finite time horizon. In these cases, outsourcing the deliveries can greatly reduce operating costs. A comprehensive review of the literature on the Inventory Routing problems can be found in [1] and [2]. We propose an exact dynamic programming algorithm (see [3]) and a matheuristic algorithm for the stochastic case. Moreover, we design an exact dynamic programming algorithm (see [3]) and a MILP-based exact dynamic programming algorithm for the robust case. The key idea consists in replacing the complete enumeration of all the realizations of the demand of the retailers and of the controls with Mixed Integer Linear Programming (MILP) models. Computational results, obtained on small and medium size benchmark instances, show the effectiveness of the proposed algorithms.

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Constructing Solution Attractor for Probabilistic Travelling Salesman Problem through Simulation

Weiqi Li*
University of Michigan-Flint, 303 E. Kearsley Street, Flint, MI 48439, USA, `weli@umflint.edu`

The probabilistic traveling salesman problem (PTSP) is a variation of the classic traveling salesman problem and one of the most significant stochastic network and routing problems. This paper proposes a simulation-based multi-start search algorithm to construct the solution attractor for the PTSP and find the best a priori tour through the solution attractor. A solution attractor drives the local search trajectories to converge into a small region in the solution space, which contains the most promising solutions to the problem. Our algorithm uses a multi-start local search process to find a set of locally optimal a priori tours, stores these tours in a so-called hit-frequency matrix E, and then finds a globally optimal a priori tour in E. In this paper, the search algorithm is implemented in a master-worker parallel architecture.

Routing of Electric Vehicles: Case Study of City Distribution in Copenhagen

Esben Linde*
DTU Transport, Technical University of Denmark, 2800 Kgs. Lyngby, Denmark,
`esli@transport.dtu.dk`

Allan Larsen
DTU Transport, Technical University of Denmark, 2800 Kgs. Lyngby, Denmark,
`ala@transport.dtu.dk`

Anders Vedsted Nørrelund
DTU Transport, Technical University of Denmark, 2800 Kgs. Lyngby, Denmark,
`ann@transport.dtu.dk`

Stefan Ropke
DTU Management Engineering, Technical University of Denmark, 2800 Kgs. Lyngby, Denmark,
`ropke@dtu.dk`

Min Wen
DDTU Transport, Technical University of Denmark, 2800 Kgs. Lyngby, Denmark,
`mw@transport.dtu.dk`

In Copenhagen, Denmark, the preliminary steps of introducing an Urban Consolidation Centre (UCC) in the perimeter of the city centre has been taken. By implementing a UCC, interests of customers and distributors, as well as improvement of the local urban environment are sought considered [1]. The UCC service aims to consolidate urban freight, as well as implement additional aspects such as off-peak delivery and utilisation of alternatively fuelled vehicles.

In the specific case of Copenhagen, a comprehensive traffic survey was conducted in May 2011. The aim of the survey was to estimate freight magnitude and the distribution of goods in the old city centre. Based on the survey, analysis of possible UCC locations was carried out using simulation.

Distribution from the UCC is assumed to be conducted with electric vehicles (EVs) as they are considered suitable for the overall aim. However, compared to conventional distribution vehicles they have a limited driving range and a limited freight capacity. In this work, an Electric Vehicle Routing Problem with Time Windows (EVRPTW) is addressed. The EVs are allowed to recharge at certain customers or replenishment stations in order to continue a tour. Furthermore, intelligent location of these recharging points is considered. The objective is to find a least cost plan for routing and recharging the vehicles so that each customer is serviced by exactly one vehicle within its time windows and the vehicle capacity and driving range constraints are satisfied. The EVRPTW is a new problem that only has received little attention in the literature; see for example [2] and [3]. The costs are compared to distribution conducted by conventional vehicles. A heuristic method is developed and tested on the data generated on the basis of real-life collected data.

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A GRASP Algorithm for a Real-World Waste Collection Problem

Ana Dolores López Sánchez*
Department of Economics, Quantitative Methods and Economic History. Pablo de Olavide University, Seville, Spain, `adlopsan@upo.es`

Abraham Duarte
Department of Computer Science. Rey Juan Carlos University. Tulipán s/n. 28933 Mótoles, Madrid, Spain, `abraham.duarte@urjc.es`

Francisco Gortázar
Department of Computer Science. Rey Juan Carlos University. Tulipán s/n. 28933 Mótoles, Madrid, Spain, `patxi.gortazar@gmail.com`

Alfredo G. Hernández-Díaz
Department of Economics, Quantitative Methods and Economic History. Pablo de Olavide University, Seville, Spain, `agarher@upo.es`

Miguel Ángel Hinojosa Ramos
Department of Economics, Quantitative Methods and Economic History. Pablo de Olavide University, Seville, Spain, `mahinram@upo.es`

A new GRASP algorithm has been implemented to solve a waste collection problem. See Feo and de [1] for details of the GRASP algorithm. The proposed algorithm has been tested over a set of medium sized instances as well as the real instance.

The real world problem addressed is the waste collection problem in Seville (Spain). Since vehicles can be only loaded from their right side, a directed graph with two distinguished nodes namely the depot (where vehicles are stored) and the landfill (where vehicles are emptied) has been considered. Each vehicle must visit streets until its capacity is reached several times during the seven-hour workday. Thus, each vehicle should perform a route combining two or more trips. In the initial trip, vehicles start at the depot and end at the landfill while the rest of the trips start and end in the landfill. A similar problem was studied in Maniezzo and Roffilli [2].

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Offshore Windfarm Infield Cable Layout: Models and Algorithms

Jens Lysgaard*
Department of Economics and Business, Aarhus University, Denmark, `lys@asb.dk`

Joanna Bauer
Department of Informatics, University of Bergen, Norway, `Joanna.Bauer@ii.uib.no`

In an offshore wind farm, the connections between turbines and transformers are provided by cables which are trenched into the seabed. Each cable connects a transformer to a number of turbines, in many cases according to a *radial* layout, i.e., in which the individual cable represents a string of turbines and with one end at a transformer.

For given locations of turbines and transformers, the Offshore Windfarm Array Cable Layout Problem (OWFACL) was introduced to us by a cable installer company as follows. Given the locations of turbines and transformers and a cable capacity measured in number of turbines, determine a minimum cost radial cable layout connecting every turbine to a transformer, subject to cable capacities and so that cables do not cross each other. Relevant costs are composed of a number of elements including cable costs as well as installation costs incurred by using the installation vessel.

Such layouts have considerable similarities with route shapes in open vehicle routing problems, viewing turbines as customers and transformers as depots. Moreover, when cable capacity is expressed as a maximum number of turbines that can be connected on a single string, the cable capacity restriction may in vehicle routing terms be expressed as capacitated vehicles and customers with unit demands. However, the no-crossing requirement is special to the OWFACL compared to standard vehicle routing models.

We consider different possibilities for modelling and solving the OWFACL and report on our computational experiments. Moreover, we outline variations of the stated problem and implications for modelling and solution methods.

A Math-Heuristic for the Green Vehicle Routing Problem

Simona Mancini*
Politecnico di Torino, Italy, `simona.mancini@polito.it`

Guido Perboli
Politecnico di Torino, Italy and CIRRELT, Montreal, `guido.perboli@polito.it`

Roberto Tadei
Politecnico di Torino, Italy, `roberto.tadei@polito.it`

In this work we address the Green Vehicle Routing Problem (GVRP). This problem is a variant of the classical VRP in which delivery operations are carried out by alternative fuel-powered vehicles, typically electrical vehicles. These vehicles yield strong environmental advantages, but also show some limits due to refueling. In fact, their fuel capacity is limited and refueling operations require time and availability of fuel stations. Therefore, refueling must be explicitly considered in the routing planning operations for these vehicles. The resulting problem can be treated as a VRP with route duration constraints, in which visits to fuel stations are allowed, when the fuel residual capacity is lower than the quantity of fuel necessary to perform the whole route. The main difference with respect to a classical VRP consists in the fact that there are some nodes which can be visited more than once or not visited at all. In fact, a node will be visited only if the residual fuel capacity is sufficient to reach a fuel station or to go back to the depot. A first formulation of this problem was given in [1], where two constructive heuristics were proposed.

In this talk we present a Math-heuristics to solve the GVRP. Starting from a feasible initial solution, our approach consists of iteratively keeping fixed $n - k$ routes and let the MIP model reoptimize the remaining k ones, where n is the total number of routes in the initial solution, and k is a parameter of the algorithm. In order to quickly solve the problem, k should assume small values. The strategy followed by the algorithm is a first improvement one, i.e. each time an improving solution is found, it is kept as current best solution. The algorithm terminates after a fixed number of iterations, or when the whole neighborhood of the current best solution has been explored without finding any improvement. The main advantage of using a MIP approach is that, at each iteration of the algorithm, we can quickly handle very large neighborhoods which would require a strong computational effort to be explored in a more traditional fashion. Computational results show the effectiveness and efficiency of the algorithm with respect to the methods available in the literature and will be presented at the conference.

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Multi-Vehicle Travelling Purchaser Problem with Exclusionary Side Constraints

Daniele Manerba*
Department of Information Engineering, University of Brescia, Brescia, Italy,
`daniele.manerba@ing.unibs.it`

Renata Mansini
Department of Information Engineering, University of Brescia, Brescia, Italy,
`renata.mansini@ing.unibs.it`

Recently, an interesting variant of the Vehicle Routing Problem (VRP), where a fleet of vehicles is available to visit suppliers offering different products at different prices and quantities, has been studied. The problem, called Multi-Vehicle Travelling Purchaser Problem (MVTPP), aims at selecting a subset of suppliers so to satisfy products demand at the minimum travelling and purchasing costs, while ensuring that the quantity collected by each vehicle does not exceed a predefined capacity (see Riera-Ledesma and Salazar-Gonzalez [1] for an application to school bus routing). More recently, Bianchessi et al. [2] study the Distance-Constrained MVTPP where a constraint ensures that the distance travelled by each vehicle does not exceed a predefined upper bound.

We introduce a generalization of the MVTPP characterized by the presence of exclusionary side constraints representing the impossibility of loading products on the same vehicle when incompatible (e.g. food and chemicals) and call it Multi-Vehicle Travelling Purchaser Problem with Exclusionary Side Constraints (MVTPP-ESC). Exclusionary constraints have been slightly studied in the literature (see e.g. Sun [3] where such constraints are added to the Transportation Problem) but, to the best of our knowledge, the complete MVTPP-ESC has never been addressed before.

The problem typically finds application in distribution logistics, more specifically in a City Logistics context where a major issue concerns the products distribution in city centers, while minimizing traffic congestion and air pollution together with purchasing cost. In particular, the problem models the practical situation where a depot is placed on border of a city center and collects, from different suppliers, products addressed to customers located inside the city. Given the variety of products requested and the similarity of the available vehicles, incompatibility constraints represent a relevant aspect of the problem.

We develop new classes of valid inequalities for the problem and propose a B&C algorithm. We also introduce a heuristic procedure that exploits some structural properties of the problem. Preliminary results on new benchmark instances seem to be very promising.

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The Stochastic and Dynamic Traveling Purchaser Problem

Renata Mansini*
Department of Information Engineering, University of Brescia, Italy, `rmansini@ing.unibs.it`
Enrico Angelelli
Department of Management, University of Brescia, Italy, `angele@eco.unibs.it`
Michele Vindigni
Department of Management, University of Brescia, Italy, `vindigni@eco.unibs.it`

Let us consider a set of n products $K := \{1, \cdots, n\}$ and a set of m markets $M := \{1, \cdots, m\}$ plus a depot 0. For each product k a positive discrete demand d_k is specified. For each market $i \in M$, $q_{ki} \geq 0$ units of product k are offered at a unit price p_{ki} depending on the market i. For each pair i, j of markets and for each market and the depot, a traveling cost c_{ij} is specified. The Traveling Purchaser Problem (TPP) looks for a tour starting at and ending to the depot that visits a subset of markets so to satisfy the demand for all products while minimizing purchasing and traveling costs (see Laporte et al. [2]).

In this paper we study a more realistic procurement setting where products quantity stochastically decreases due to other purchasers competing on the same products. The global effect of the competitors behavior is assumed to be modeled as an array of $m \times n$ stochastic consumption processes independent with respect to the m markets and the n products. The problem is also dynamic since information on quantity availability is revealed over time and the decision maker may react to new information by making new plans. We call this problem the Stochastic Dynamic Traveling Purchaser Problem (SDTPP). The problem finds application in different contexts including procurement and large scale emergencies, as those caused by natural disasters, viral spread diseases and/or terrorist attacks. To the best of our knowledge, this version of the TPP has never been addressed before. In Angelelli et al. [1] a simpler variant is studied where no assumption is made on the consumption processes and the decision maker is assumed to be informed in real-time of all occurring events.

We will explore the SDTPP under four different operating scenarios all characterized by the presence of a *planner* who has computing power and makes decisions and an *executor* (the purchaser) who runs the service in practice and has a very limited or null computing power. Scenarios differ for the *communication tools* used between planner and executor, and for the *level of information* available on the state of the world. As far as communication is concerned, different situations can be figured out ranging from the case where no communication technologies are available (after leaving the depot communication between planner and executor is interrupted) to a complete communication between actors. In terms of information, possible situations range from a minimum, characterized by knowledge of the initial state of the world plus an update collected on the field at visited markets, to a maximum like in internet based systems, where current stock levels of all markets are shared by all commercial partners in real time.

The contributions provided are multifold. We introduce two *consumption models* to estimate products inventory and propose three solution approaches, a stochastic, a deterministic and an hybrid one. The proposed approaches have been compared under the analyzed scenarios in terms of both feasibility and total costs. A comparison with a known approach proposed in the literature is also considered. Extensive computational results show how the hybrid approach provides the best compromise in terms of computational burden and quality of the solution and define interesting guidelines for decision makers involved with similar problems.

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Heuristics for the Team Orienteering Problem with Time Windows and Flexible Fleet

Fraser McLeod*
Transportation, University of Southampton, Highfield Southampton, SO17 1BJ,
`f.n.mcleod@soton.ac.uk`

Güneş Erdoğan
Management, University of Southampton, Highfield Southampton, SO17 1BJ, `g.erdogan@soton.ac.uk`

Tom Cherrett
Transportation, University of Southampton, Highfield Southampton, SO17 1BJ,
`t.j.cherrett@soton.ac.uk`

Tolga Bektaş
Management, University of Southampton, Highfield Southampton, SO17 1BJ, `t.bektas@soton.ac.uk`

This paper compares the performance of two alternative solution methods one employing tabu search, the other variable neighbourhood search on a real-life collection problem involving a heterogeneous and flexible fleet servicing charity donation banks and high street shops. The problem is modelled as a series of one-day vehicle scheduling and routing problems where the objective is to maximise profit for the day in question, where profit is calculated as the estimated value of the goods (e.g. clothes, books) collected minus the associated transport costs. A minimum collection parameter was used to ensure that visits to banks and shops did not take place too soon (e.g. not before the site was 50% full). A penalty function was also used to ensure that all sites were serviced in good time and time window constraints also applied to some of the shops. The problem is summarised as a team orienteering problem with time windows and a heterogeneous and flexible fleet.

The problem is inspired by a major UK charitys recent decision to trial remote monitoring sensors across a subset of its donation banks to improve visibility of collection requirements. This is important to the charity as collection costs can account for up to 20% of its overall revenue. Results from the tabu search method have suggested time and distance savings of up to 30% over the current fixed schedules when a minimum bank and shop fill level of between 50% and 60% was used as a collection trigger. This is comparable to results found in related applications [1], [2]. For the case study investigated, this led to a potential profit gain of 5% for the charity and estimated CO2 savings of around 1 tonne per week across the fleet of six vehicles. Results for the variable neighbourhood search algorithm will be obtained soon for comparison.

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A Column Generation Approach for Strategic Planning in LTL Logistics

J. Fabian Meier*
Institute of Transport Logistics, TU Dortmund, 44227 Dortmund, Germany,
`Meier@itl.tu-dortmund.de`

Frank Baumann
Fakultät für Mathematik, TU Dortmund, 44221 Dortmund, Germany,
`Frank.Baumann@tu-dortmund.de`

Christoph Buchheim
Fakultät für Mathematik, TU Dortmund, 44221 Dortmund, Germany,
`Christoph.Buchheim@tu-dortmund.de`

Uwe Clausen
Institute of Transport Logistics, TU Dortmund, 44227 Dortmund, Germany,
`Uwe.Clausen@iml.fraunhofer.de`

In less-than-truckload logistics small shipments have to be transported between depots. By consolidating truckloads in depots along the way, significant savings in shipment costs can be achieved. The aim of strategic planning is to determine routings and transport capacities that balance transport costs and transshipment costs.

We model this problem as a directed network loading problem [2] with integer capacities. A solution of this model determines a unique route through the network for each shipment and the number of trucks needed between each pair of depots. In the specific application we consider, shipments may be turned over at most twice. Already in its original version the network loading problem is NP-hard. In our application capacities correspond to trucks and have to be integer, which leads to a further increase of complexity from a practical point of view.

We propose a column generation approach that is able to compute good feasible solutions in reasonable time. For small instances it is able to compute exact optimal solutions. For larger instances it can be used as a heuristic by limiting the number of columns generated. Starting with a small subset of the possible routes, we solve the network loading problem with an LP-based branch and bound-algorithm. In each node of the branch and bound-tree promising routes can be added dynamically. In our application this pricing problem consists of computing hop-constrained shortest paths in the network. The branch and bound-algorithm is combined with a rounding heuristic that computes feasible solutions from the fractional solutions of the LP-relaxations. For that we use a repair function that finds locally optimal routes for unrouted commodities. Considering far-from-integer routes as unrouted, we can use it to find an integer solution. Furthermore, by actively destroying and repairing some parts of the solution, we can find neighbours of the given solution so that we can apply a local search meta-heuristic. To generate a good set of starting variables for the column generation approach we use a more involved heuristic [1]: It derives its initial solution from a restricted problem which assumes that bundled goods will not be debundled again and hence represents the paths to each depot by a tree. Afterwards, it uses local search techniques to improve this solution. First tests on real-life instances show that our approach is able to produce good feasible solutions in reasonable time.

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Continuous Monitoring Problem for Disaster Management

Vera Mersheeva*
Institute of Applied Informatics, Alpen-Adria-Universität,
Universitätsstraße, 65-67, 9020 Klagenfurt, Austria, `vera.mersheeva@uni-klu.ac.at`

Gerhard Friedrich
Institute of Applied Informatics, Alpen-Adria-Universität,
Universitätsstraße, 65-67, 9020 Klagenfurt, Austria, `gerhard.friedrich@uni-klu.ac.at`

To handle a disaster situation immediate response of a rescue team is required. Lack of information at the beginning of the rescue mission can lead to serious consequences. Ground observations by rescuers might be impossible in a complex terrain. Usage of a helicopter could be unfeasible due to high expenses, availability of a trained pilot, etc. Therefore, in the project "Collaborative microdrones" [1] we have developed a system based on micro unmanned aerial vehicles (micro-UAVs) to provide a birds-eye-view of the terrain. These drones are affordable and easy to transport, deploy and maintain.

A micro-UAV cannot take picture of a large area in a single shot. Thus, the area is divided into clusters so that each of them can be covered by a single picture. In order to provide an overview image and its updates, drones have to constantly fly over the area in the most efficient way. We introduced Continuous Monitoring Problem (CMP) to model this task [2].

In CMP an area of interest is represented as a set of picture points and base stations. A picture point is a location where a drone takes a photo of a cluster. A base station is a location on the ground where the drones take off and land, and their spare batteries are stored. A fleet of heterogeneous drones is located at some of the points or stations. A drone of each type has a certain flight speed and a limited battery capacity. The goal is to compute a set of routes for a fleet such that each point is visited as often as possible and time delays between revisits are minimal.

In this talk we will describe our algorithms that efficiently solve both CMP[2] and CMP with inter-depot routes (CMPID). The basis of these algorithms is the well-known metaheuristic Variable Neighbourhood Search (VNS) [3]. It iteratively improves an initial solution that is computed by our effective modification of Clarke and Wright algorithm [4] or one of our adaptations of the Solomon's insertion heuristic [5]. We extend the VNS by adding new operators and choose the most efficient neighborhood structure.

The mentioned methods were evaluated on different sets of instances. They showed near-optimal results on instances where optimum can be found. The solutions are 26.9% and 11.93% far from optimum for CMP and CMPID respectively. Moreover, good solution can be provided just in a few seconds. Thus, they can be applied to disaster response missions.

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Synchromodal Transport Planning

Martijn Mes[*]
School of Management and Governance, University of Twente, P.O. Box 217, 7500 AE Enschede, The Netherlands, `m.r.k.mes@utwente.nl`

Rick van Urk
School of Management and Governance, University of Twente, P.O. Box 217, 7500 AE Enschede, The Netherlands, `r.vanurk@utwente.nl`

In this paper, we consider the planning of synchromodal transport with the objective to minimize costs and CO_2 emissions, while maintaining delivery reliability. Synchromodal transport is a form of multimodal transport in which the best possible combination of transport modes is selected for every order, and the choice of modality might even change during transport. A shipper agrees with a logistics service provider (LSP) on the delivery of products at specified costs, duration, and sustainability but gives the LSP the freedom to decide on how to deliver according to these specifications. This provides freedom to the LSP to deploy different transport modes flexibly depending on real-time information on traffic conditions and resource availability. Synchromodal planning offers the opportunity to improve transportation services by operating more sustainable, at lower costs, and at higher quality.

We propose a planning algorithm for synchromodal transport. The underlying problem is related to the shortest path problem, which can be solved exact in quadratic time. However, the goal of our algorithm is to provide the decision maker with a list of the top k multimodal routes, which is related to the k-shortest paths problem [1]. More precisely, our problem is related to the multi-objective k-shortest paths problem (see, e.g., [2]) because we have to balance between costs, emissions and delivery punctuality. Additional complexity is introduced in the form of (i) the decision which carrier to use on which leg at what time, (ii) soft time-windows, (iii) pre-defined time-tables for rail and barge transport causing variable waiting times, (iv) contractual agreements, (v) complex costs functions depending on time, weight and volume, and (vi) the possibility of freight consolidation.

The complexity of our algorithm depends on the number of legs available for transport, where a leg is a combination of a direct connection between two hubs (points where we can switch modality), a carrier operating on this connection, and possibly a pre-defined departure and arrival time. Obviously, for realistic planning problems, the number of legs that serves as input for our algorithm is huge and enumerating all routes would simply be impossible. Therefore, we propose a sequential procedure where we iterate on the number of legs included in a route. In each iteration, we extend the routes from the previous iteration by replacing the last leg with two new legs. Before storing a newly generated route, it first has to pass various multi-objective checks, thereby limiting the amount of routes to be generated in each iteration.

We illustrate our approach using a case study at Seacon Logistics, a LSP located in the Netherlands. Using two years of order data on two of the main corridors of this company, we compare actual multimodal transport of this company with synchromodal transport driven by our algorithm. Using simulation, we show that our approach considerably improves the objectives costs and CO_2 emissions, while maintaining delivery reliability. Seacon Logistics is now in the process of changing their business to adapt a synchromodal planning methodology using our algorithm.

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A Powerful Large Neighborhood Search for the Vehicle Routing Problem with Time Windows

David Mester*
Institute of Evolution, Mathematical and Population Genetics Laboratory, University of Haifa, 31905 Haifa, Israel., `dmester@research.haifa.ac.il`

Olli Bräysy
Faculty of Economics and Business Administration, VU University Amsterdam, De Boelelaan 1105, 1081 HV, Amsterdam, Netherlands., `olli.braysy@vu.nl`

Wout Dullaert
Faculty of Economics and Business Administration, VU University Amsterdam, De Boelelaan 1105, 1081 HV, Amsterdam, Netherlands
Institute of Transport and Maritime Management Antwerp, University of Antwerp, Kipdorp 59, 2000 Antwerp, Belgium, `wout.dullaert@vu.nl`

We suggest a new two-phase metaheuristic for the well-known vehicle routing problem with time windows. The initial solution is first generated with a simple variant of the cheapest insertion heuristic. The key idea is to combine large neighborhood search with standard guided local search metaheuristic in a novel way, allowing improved search diversification and escape from local minima in more efficient way. The search is further improved by varying geographical limitations and two simple local search operators. A restart strategy from the best found solution is also included to direct the search. The algorithm has been tested on the standard Gehring and Homberger benchmarks and the preliminary results indicate very competitive performance. We found a lot of new and matched best-known solutions for all problem sizes at comparable computation times.

A Metaheuristic Approach for a Vehicle Routing Problem Arising in a Real Used-Oil Collection Project

Roberto Montemanni[*]
Dalle Molle Institute for Artificial Intelligence (IDSIA - USI/SUPSI), 6928 Manno, Switzerland,
`roberto@idsia.ch`

Matteo Salani
Dalle Molle Institute for Artificial Intelligence (IDSIA - USI/SUPSI), 6928 Manno, Switzerland,
`matteo.salani@idsia.ch`

Dennis Weyland
Dalle Molle Institute for Artificial Intelligence (IDSIA - USI/SUPSI), 6928 Manno, Switzerland,
`dennis@idsia.ch`

Luca Maria Gambardella
Dalle Molle Institute for Artificial Intelligence (IDSIA - USI/SUPSI), 6928 Manno, Switzerland,
`luca@idsia.ch`

Caritas Suisse recently started a project for the recycling of used cooking oil into bio diesel fuel in the touristic area of Bali, Indonesia. In this region large quantities of used cooking oil are accumulated in restaurants and hotels. The appropriate disposal of this cooking oil is still an unsolved problem and an inappropriate disposal leads to some problems, ranging from the pollution of water up to health risks caused by reusing cooking oil too many times. The basic idea of the project is to organize and perform a collection of the exhausted cooking oil and to recycle it into bio diesel fuel. Oil is accumulated by cooperating hotels and restaurants and regularly collected and brought to a processing plant. At this plant, the oil is transformed into biofuel. In this way an appropriate disposal of the old cooking oil is ensured. Different benefits are guaranteed by the project. The environment in Bali is protected, while risks for the health that are caused by reusing cooking oil are reduced. Furthermore, the project helps the people living in Bali by creating some new job opportunities. A certain quantity of conventional fuel can be substituted by the bio diesel obtained during the recycling process. Finally, a contribution for the combat against climate change is made. Summarizing the benefits, the project has potentials both in helping the local people and in protecting the environment.

We will discuss how the transportation component of the oil collection project can be modeled as a particular Vehicle Routing Problem with special side constraints. We will then propose a tailored metaheuristic to tackle the problem. We will finally present an experimental study where the metaheuristic is run on a first prototypal version of the real data of the project. The results of such a study have been used to dimension the fleet of vehicles and to select the location of the processing plant, which had to be chosen among three possible alternatives. More details can be found in [1].

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Arc Routing Solutions to a Case Study

Maria Cândida Mourão*
CIO & Dep. Matemática, Instituto Superior de Economia e Gestão, Universidade Técnica de Lisboa, Lisboa, Portugal, `cmourao@iseg.utl.pt`

Leonor Santiago Pinto
CEMAPRE & Dep. Matemática, Instituto Superior de Economia e Gestão, Universidade Técnica de Lisboa, Lisboa, Portugal, `lspinto@iseg.utl.pt`

Arc routing problems (ARP), which are known to be NP-hard [1], have been applied to solve several real world applications. Household refuse collection problems, usually dealing with vehicles with limited capacities and over street maps, lead to the more general Mixed Capacitated ARP (MCARP). Arc routing topics are well outlined in both [2] and in the Drors book [3].

In this presentation a three-phase heuristic method is described: I) at the first phase a problem relaxation is solved; II) at the second phase some services are fixed, following an heuristic that looks to the solution of phase I); III) at the end, and given the services previously fixed, a valid model is solved to find the a set of feasible trips. Models in phases I and III are based on compact ones proposed in [4], and solved by the CPLEX. The relaxation, although not valid, provides good bounds. Its solution is then used to help to reduce instances size, as some services are fixed somehow accordingly the relaxed solution. A valid model may then be applied to smaller sized instances. This model fails to find feasible solutions for the bigger instances, thus requiring these instances reductions.

The method is applied to a Portuguese municipality, Seixal, demanding for new set of constraints, as, e.g., to ensure a set of balanced vehicle trips. Data sets from this municipality are used to evaluate the quality of the solutions. The performance of the heuristics is also benchmarked against some well-known MCARP instance.

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Earthwork Optimization Models for the Construction of a Large Highway System

Stefano Novellani*
DEI, Univ. of Bologna, `stefano.novellani2@unibo.it`
Christian Bogenberger
BPM, STRABAG, `christian.bogenberger@strabag.com`
Mauro Dell'Amico
DISMI, Univ. of Modena and Reggio Emilia, `mauro.dellamico@unimore.it`
Gerhard Hoefinger
BPM, STRABAG, `gerhard.hoefinger@strabag.com`
Manuel Iori
DISMI, Univ. of Modena and Reggio Emilia, `manuel.iori@unimore.it`
Barbara Panicucci
DISMI, Univ. of Modena and Reggio Emilia, `barbara.panicucci@unimore.it`

We describe the activity we performed when modeling the construction of a large highway system in the urban area of Milan, in Northern Italy. The highway system takes the name of *Autostrada Pedemontana Lombarda*, it counts more than 50 km in length and it is made of several access rumps, junctions and local streets. According to the fact that the new highway will pass through densely populated areas, the majority of the street is going to be built in trench, a few meters under the ground level. This implies that a huge amount of earth (about tens of millions of cubic meters), of diverse types and quality, has to be dug and moved to different locations by means of special excavators and trucks.

The goal of our work has been to devise a support tool that aids managers to schedule the construction activities. These involve decisions on the use of several quarries and dump sites, the temporary rent of landfill areas, the installation of recycling and mixing plants, and the use of a large fleet of vehicles to dig and move earth. The final outcome of the tool we developed includes the amount of quantity of each material that must be moved in each time period, its origin and its destination, and allows to obtain a target profile of the overall construction process in the planning horizon at minimum cost.

The problem is far from being trivial. The construction of a highway includes indeed various activities to be done in different periods of the planned horizon and each activity has its own time window to be respected.

The goal of the optimization is to decide when and how moving the materials, by responding to digging and filling requests deriving from excavation and building activities. We also aim at minimizing costs of transportation and costs of material bought from quarries and brought to dump sites.

The optimization approach we used is a network flow optimization. The highway building site has been modeled as a graph, in which vertices correspond to locations, and facilities. Furthermore some public network has been considered to model the connections with external facilities.

The approach contemplates an aggregate formulation and a disaggregate one. The aggregate formulation is a linear programming model, that considers the cumulate flows on the arcs of the network with the main objective of providing feasible solutions. It can be run many times by making use of a rolling horizon perspective in order to take into consideration the evolution of the activity. The disaggregate model is also a linear programming model. It takes in input the solution of the aggregate formulation and finds the best way to divide the cumulate flows of each material in each period.

Despite the use of linear programming, the models may need large computing times, because they typically involve hundreds of thousands of variables and constraints. In this work we describe the problem and the modeling activity in details. We give some hints on the behavior of the models on the real-world case study, and we then present detailed computational results on an case study example that we collected.

Estimating the Cost of Continuity of Care in Home Health Care Delivery

Maciek Nowak*
Information Systems and Operations Management, Graduate School of Business, Loyola University, Chicago, IL, 60611, `mnowak4@luc.edu`

Mike Hewitt
Department of Industrial and Systems Engineering, Rochester Institute of Technology, Rochester, NY 14534, `mrheie@rit.edu`

Many transportation or delivery organizations use multiple metrics to evaluate their schedules and routes. Some are external, or customer-facing, some are internal, such as distribution of work across employees, but for most organizations cost is first considered when making decisions. However, when it comes to health care one could claim that care-related metrics should be considered as much as, if not more than, operating costs.

In this paper we study the relationship between quality of care-related metrics and cost for agencies that deliver health care in the home. When measuring the quality of care they provide, one metric often considered by home health care agencies is what is known as "continuity of care," namely that a patient should be seen by the same care provider as often as possible. A newer metric that agencies are beginning to consider is continuity with respect to time; that a patient should be quoted a time window and then always visited during that window. While continuity of care has long been considered to be correlated with quality of care, particularly as new metrics related to continuity of care are considered, understanding the associated costs can lead to more informed decision-making for a home health care agency, which, at this time, is critical. This is what we address here.

From an operations research perspective, the problem faced by a home health care agency is a multi-depot, multi-period, capacitated vehicle routing problem (VRP) with time-windows and continuity constraints linking the periods. The problem is multi-depot because many care providers begin and end their day in their own home. The problem is multi-period because a patient is typically seen multiple days in a week for a 60 or 90-day care period. In this problem, capacity is with respect to the number of hours a care provider works in a day and reflected in two constraints, the first capturing when an overtime rate should apply and the second enforcing a maximum number of hours per day. Lastly, unlike most VRPs with time windows, in this problem the time windows during which a patient is visited are quoted by the agency.

In this paper a methodology to analyze the trade-off between transportation cost and continuity of care metrics is developed. To re-iterate, the metrics considered are the number of different caregivers who visit a patient, referred to as *caregiver continuity*, and the number of different time windows during which a patient is visited, referred to as *time window continuity.* The work of Groer et al. (2009) on the Consistent VRP considers *caregiver continuity* and a model of *time window continuity* using hard constraints that are not strictly enforced for a solution. The model presented in this paper treats *time window continuity* as an objective of a multi-objective optimization problem. The work of Smilowitz et al. (2013) treats *caregiver continuity* in a multi-objective sense, but does not consider *time window continuity.* In the VRP literature, we believe this is the first paper to model the choice of consistent time windows for when a customer is visited.

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Tonnage Allocation in Dry Bulk Liner Shipping

Bjørn Nygreen*
Industrial Economics and Technology Management, Norwegian University of Science and Technology, NO-7491 Trondheim, Norway, `bjorn.nygreen@iot.ntnu.no`

Øydis Kristine Flateby
Industrial Economics and Technology Management, Norwegian University of Science and Technology, NO-7491 Trondheim, Norway, `flateby@stud.ntnu.no`

Inge Norstad
Norwegian Marine Technology Research Institute (MARINTEK), NO-7450 Trondheim, Norway, `inge.norstad@marintek.sintef.no`

Here, we describe a planning problem for a shipping company that transports dry bulk cargoes mainly between known suppliers and known customers. The company has contractual obligations to transport given amounts of specific cargoes between given pairs of pickup and delivery ports during a year. Each contract usually specifies how many deliveries there should be during the year and how flexible each delivery can be both in time and amount. Nearly all the contracts have their pickup and delivery ports in different regions of world. From this the company has grouped their contracts into trades. A trade is defined by the common pickup region and the common delivery region for all the contracts in the trade. All contracts in a trade do not need the same number of deliveries during a year.

The companys planning problem can be divided into three levels:

Level 1: Decide how many voyages to sail on each trade and a time window for start of each voyage.

Level 2: Decide which ship to sail each voyage. This includes routing of the ships between voyages.

Level 3: Plan each voyage. This means decisions about port visits, schedules and cargo amounts.

This talk will be based on current master project related to decision support tools for Level 2. The contractual demand for ships is not constant. The shipping company tries to adapt to this in two ways. 1) The company includes the possibility to hire spot ships to sail some of their planned voyages and 2) they define optional trades in their planning model. An optional trade consists of a voyage with some earning possibilities between regions where the ship otherwise would have sailed in ballast.

The company controls a fleet of 28 ships and a planning horizon of four months typically includes assigning and scheduling 60-70 contractual voyages.

Computational results for a MIP model solved with standard commercial software will be discussed for different specifications of the contractual flexibility regarding amounts and timing. Some of the timing issues are discussed in the references beneath.

Optimization of Patient Transportation — Solving an Extension of the Heterogeneous Multi Depot Dial-A-Ride Problem with Tabu Search Variants

Marco Oberscheider*
Institute of Production and Logistics, University of Natural Resources and Life Sciences, Vienna
Feistmantelstraße 4, 1180 Vienna, Austria, `marco.oberscheider@boku.ac.at`
Patrick Hirsch
Institute of Production and Logistics, University of Natural Resources and Life Sciences, Vienna
Feistmantelstraße 4, 1180 Vienna, Austria, `patrick.hirsch@boku.ac.at`

The costs of patient transportation and emergency rescue services in Austria have increased steadily over the past 20 years. They tripled since 1990 and due to the predominant demographic trend, there is a high probability of a further increase in future. In order to cover the needs of the ageing society in industrialized countries, efficient planning is crucial for providers of these services. Hence, the aim of minimizing operating times of used vehicles for patient transportation was formulated in cooperation with a main provider in Austria. The planning is done on a daily basis and the algorithms are tested with real-life data.

The underlying problem can be characterized as an extension of the static heterogeneous dial-a-ride problem [1]. It is specified by multiple depots with a varying number of heterogeneous vehicles. Vehicles start at their depots on their first requested service and have to return after a specified shift length. According to Austrian law, mandatory breaks have to be taken depending on the shift length. With Vehicles of type A up to three ambulant patients can be served and with vehicles of type B it is possible to transport a maximum of two patients with different types of mobility - ambulant, with a stretcher or with a wheelchair. Due to the equipment of type B vehicles, it is not possible to transport two patients who are in need of a stretcher at the same time. Therefore, the pickup of a preceding patient is depending on the current load status of the vehicle. Additionally, the duration for manipulation of patients at pickup or delivery nodes depends on the type of mobility, vehicle type, the combination of patients and the pickup or delivery locations (e.g. nursing homes, hospitals or wards). These durations are derived from statistical analyses. Time windows are given at pickup locations and in addition the extension of the ride time of one patient, due to the service of additional patients, is restricted.

The first step of the solution approach is the enumeration of all feasible combinations of patient transports by a recursive depth-first search. These feasible combinations are called tasks and can be formed by observing the given constraints. After the tasks are identified, they are combined to a feasible solution by solving a set partitioning problem with the objective of minimizing operating times. Subsequently, these tasks are heuristically assigned to shifts to generate an initial solution for two Tabu Search strategies. Namely, an adaptation of the Unified Tabu Search [2] and a Tabu Search strategy with a dynamically alternating neighborhood structure [3]. This solution approach has been tested in different scenarios on real-life instances with up to 374 transports and 72 available vehicles. The results are compared to the current state in an ex-post analysis.

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A Cycle-Based Evolutionary Algorithm for the Multi-Commodity Network Design Problem

Dimitris Paraskevopoulos*
School of Management, University of Bath, Claverton down, Bath, UK, BA2 7AY, `dp465@bath.ac.uk`

Tolga Bektaş
School of Management, Centre for Operational Research, Management Science and Information Systems (CORMSIS), University of Southampton, Southampton, Highfield, SO17 1BJ, UK,
`t.bektas@soton.ac.uk`

Teodor Gabriel Crainic
Département Management et Technologie, École des Sciences de la Gestion, Interuniversity Research Centre on Enterprise Networks, Logistics and Transportation (CIRRELT), Université du Québec à Montréal, C.P. 8888, succ. Centre-ville, Montréal QC Canada H3C 3P8,
`TeodorGabriel.Crainic@cirrelt.ca`

Chris Potts
School of Mathematics, Centre for Operational Research, Management Science and Information Systems (CORMSIS), University of Southampton, Southampton, Highfield, SO17 1BJ, UK,
`c.n.potts@soton.ac.uk`

This paper presents a cycle-based evolutionary algorithm (CEA) for solving the fixed-charge multi-commodity network design problem (MCNDP), which concerns routing multiple commodities from origins to destinations by designing a network through selecting arcs, with an objective of minimizing the fixed costs of the selected arcs plus the variable costs of the flows on each arc.

Despite the significant efforts devoted to the development of exact methodologies for the MCNDP [1], the literature still favours heuristic approaches when large-scale problem instances are involved. One of the most successful local search strategies for the MCNDP is proposed by [2], where cycle-based neighborhood operators are incorporated in a tabu search framework. The main idea of the cycle-based local moves is to redirect commodity flows around cycles in order to remove existing arcs from the network and replace them with new arcs.

Inspired and motivated by the advances in the heuristic approaches for the MCNDP, this paper contributes to the existing body of work by: (i) proposing an efficient iterated local search (ILS) that utilizes new and enhanced cycle-based neighbourhood operators, long and short term memory structures, and an innovative perturbation strategy based on ejection chains [3] that aims at guiding the search towards unexplored solution neighbourhoods; and (ii) presenting an efficient Scatter Search that dynamically adjusts the preferences for inherited solutions based on the search history.

Computational experiments on the benchmark instances of [4] show that the proposed CEA is quite competitive compared to state-of-the-art approaches. On average (of all the 43 benchmark instances), CEA performs better than all the heuristics in the literature, while remaining competitive when compared to the algorithm of [1]. It is also able to produce two new best solutions of large-scale problems, with regard to the best known solutions obtained by heuristics.

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Residential Waste Collection in Urban Environments

Dimitris Paraskevopoulos*
School of Management, University of Bath, Claverton down, Bath, UK, BA2 7AY, `dp465@bath.ac.uk`

Panagiotis Repoussis
Howe School of Technology Management, Stevens Institute of Technology, Castle Point on Hudson, Babbio Center, Hoboken, NJ 07030, `prepouss@stevens.edu`

Christos Tarantilis
Operations Research Center, Management Science Laboratory, Department of Management Science and Technology, Athens University of Economics and Business, Athens, Greece, 10434, `tarantil@aueb.gr`

This paper is based on a research project that focuses on the development of solution methodologies for the residential waste collection problem (WCP) in the city of Athens, Greece. We refer to [1] for a comprehensive literature review on waste collection and management problems. The incumbent problem addressed herein can be described as follows.

All waste producers of the city of Athens are serviced through a large scale municipal-wide network of garbage containers. The collection of solid waste from the network of garbage containers and the transportation of the collected waste to the appropriate disposal facilities (e.g. disposal sites, mechanical recycling sites and recyclable waste treatment sites) is performed via a heterogeneous fleet of waste collection vehicles on a 24/365 basis. From the operational viewpoint, each waste collection vehicle serves a particular set of street segments, called waste collection sectors, assuming two disposal trips with predefined route duration, accessibility and capacity constraints. The goal is first to find the optimum clustering of street segments and assignment of different vehicle types to each sector and second to design minimum cost vehicle routes, i.e., to find the service sequence of garbage containers, such that the utilization of available resources is maximized with the least possible operational cost. The resulting combined arc-routing and sectoring problem raises major theoretical and computational research challenges. What complicates matters more is the heterogeneous vehicle assignment sub-problem to each waste collection sector due to accessibility restrictions. All critical aspects and concerns of the problem are taken into account, including shortest paths and distances between all pairs of street segments, vehicle's average speeds, service times, disposal trips times, various vehicle capacities and available fleet size and mix.

The study by [2] proposed two insertion-based heuristic methods for addressing the sectoring arc routing problem, faced in urban waste management. Their solution approach tackles the sectoring and the routing phase simultaneously and considers additional objectives other than this of traveled distance. In this paper, the WCP was divided in two separate but interrelated problems; the problem of designing the waste collection sectors and the problem of the available vehicle fleet assignment to particular sectors and the design of the waste collection routes. For each part of the problem solved, a tailor-made solution method has been developed that takes advantage of the peculiarities of each problem. Regarding the sectoring problem, a Tabu search method has been developed to produce compact and feasible in terms of accessibility and route duration constraints sectors. With regard to the related arc routing problem a hybrid evolutionary algorithm has been developed to minimise the total travelled distance.

The urban environment to serve as a test bed for our solution methodologies, was the city of Athens in Greece. Given the explosive computational complexity and the combinatorial nature of the problem, high quality solutions are produced with modest computational burdens to a wide variety of very large-scale problem instances, according to a predefined set of the specifications.

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The Recurring Fleet Size and Mix Vehicle Routing Problem (R-FSMVRP)

Urooj Pasha[*]
Faculty of Economics, Informatics and Social Sciences, Molde University College, Specialized University in Logistics, P.O. Box 2110, N-6402, Molde, Norway , `urooj.pasha@himolde.no`

Arild Hoff
Faculty of Economics, Informatics and Social Sciences, Molde University College, Specialized University in Logistics, P.O. Box 2110, N-6402, Molde, Norway, `arild.hoff@himolde.no`

Arne Løkketangen
Faculty of Economics, Informatics and Social Sciences, Molde University College, Specialized University in Logistics, P.O. Box 2110, N-6402, Molde, Norway, `arne.lokketangen@himolde.no`

We are introducing a novel variation of the Fleet Size and Mix Vehicle Routing Problem (FSMVRP) [1] which has been little studied. The decisions involved in FSMVRP are important and are getting increasing attention from industry due to practical relevance. Transport providers may have several options in sizes and capacities to choose from when investing in vehicles. Most transport companies use a heterogeneous vehicle fleet mix. This is partly due to the acquisition of vehicles over time. The overall problem is then to have a fleet-mix that maximizes the profit over time.

In the FSMVRP, vehicles with different sizes and capacities, and associated costs, are available in sufficient numbers. Usually, for the FSMVRP, a single day VRP is solved, and a (near-) optimal vehicle fleet mix is found for that day or instance. A more realistic setting is when we know the demand of the customers for a prolonged period of time, like a week or a month, and want to find a fleet mix that is optimal over this period.

We define the Recurring Fleet Size and Mix Vehicle Routing Problem (R-FSMVRP), where the chosen fleet size and mix is repeatedly used on a set of distinct scenarios or single day FSMVRP's. This is a deterministic problem, consisting of a set of similar FSMVRP's, with the added global constraint that the same fleet size and mix should be used for all the scenarios. This problem thus models the real world problem more realistically.

An extended set of instances based on the instances in Golden [1] have been generated, using the same underlying probabilities for the demand, and consist of weekly (5 day) and monthly (20 day) instances. We have developed a Tabu Search based solver for these problems, and extensive results will be presented.

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Compound Neighborhood Structures for Heterogeneous Vehicle Routing Problems

Puca Huachi Vaz Penna*
Departamento de Ciências Exatas, Biológicas e da Terra/INF, Universidade Federal Fluminense, Rua João Jazbik s/n, Santo Antônio de Pádua-RJ, 28470-000, Brazil, `ppenna@ic.uff.br`

Thibaut Vidal
Instituto de Computação, Universidade Federal Fluminense, Rua Passo da Pátria 156, Bl E - 3º andar, São Domingos, Niterói-RJ, 24210-240, Brazil
COPPE, Universidade Federal do Rio de Janeiro, Rio de Janeiro, Brazil, `thibaut.vidal@cirrelt.ca`

Anand Subramanian
Departamento de Engenharia de Producção, Universidade Federal da Paraíba, Centro de Tecnologia, Bl G, Cid. Universitária, João Pessoa-PB 58051-970, Brazil,, `anand@ct.ufpb.br`

Luiz Satoru Ochi
Instituto de Computação, Universidade Federal Fluminense, Rua Passo da Pátria 156, Bl E - 3º andar, São Domingos, Niterói-RJ, 24210-240, Brazil
COPPE, Universidade Federal do Rio de Janeiro, Rio de Janeiro, Brazil, `satoru@ic.uff.br`

Christian Prins
Institut Charles Delaunay (FRE CNRS 2848), Université de Technologie de Troyes BP 2060, 12 rue Marie Curie, 10010 Troyes Cedex, France, `christian.prins@utt.fr`

The Heterogeneous Vehicle Routing Problem (HVRP) is a generalization of the Capacitated Vehicle Routing Problem (CVRP), in which customers are served by a heterogeneous fleet composed of a limited number of vehicles. This variant also includes fixed and dependent costs. The problem is NP-hard since it includes the CVRP as a special case. The objective is to design a set of routes in such a way that the sum of the travel costs is minimized.

In this scope, the selection of an adequate vehicle type for each route is essential to obtain high-quality solutions. Most local search-based methods from the literature are based on independent neighborhood structures for optimizing the visit sequences (routes), and the assignment of routes to vehicles. In this presentation, we introduce a new Compound Neighborhood Structure (CNS) for the problem. The CNS combines reallocation and swap moves with a problem-tailored procedure for optimizing the assignment. Thus, a relocate or swap move, which appeared as non-improving without any change of vehicle type, can lead to significant improvements when route-to-vehicle re-assignments are allowed. Two procedures are presented to efficiently optimize the assignment decisions during the search. The first one is based on a Primal-dual algorithm and the second one is a relaxed implementation, which only takes into account the routes involved in the move itself and the available set of vehicles during the assignment process.

The proposed neighborhood search is integrated in a metaheuristic framework based on Iterated Local Search with Variable Neighborhood Descent and Random Neighborhood Ordering (ILS-RVND) [1]. Extensive empirical studies are conducted to assess on the impact of the CNS with different assignment procedures. The results demonstrate the positive impact of the CNS on solution quality. This impact is even more significant when the fleet of vehicles is strongly heterogeneous with no linear dependence between vehicles capacity and the costs. In addition, new best known solutions are generated for several well-known HVRP benchmark instances.

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Transfer Synchronisation in Multimodal Corridors

Hanne L. Petersen[*]
DTU Transport, Technical University of Denmark, Copenhagen, `hlp@transport.dtu.dk`

Federico Farina
DTU Transport, Technical University of Denmark, Copenhagen, `fedfa@transport.dtu.dk`

Rune Larsen
DTU Transport, Technical University of Denmark, Copenhagen, `rular@transport.dtu.dk`

Allan Olsen
DTU Transport, Technical University of Denmark, Copenhagen, `aol@transport.dtu.dk`

Green corridors and intermodality have become focus areas of the European Union in recent years. The GreCor project investigates green corridors in the North Sea and Baltic region. The aim of a corridor is to provide an efficient way of using multimodal transportation. This requires the availability of well-functioning transfer opportunities, which in turn requires coordinated schedules in order to allow for smooth and fast transfers. The aim of a green corridor is to ensure that there exists an attractive and viable alternative to truck transportation, e.g. by use of rail and sea transport. As the focus region of this project is centered around a land-enclosed sea, multimodal freight transportation combining sea and other modes becomes a natural choice.

The network considered here consists of a combination of rail, sea and road, i.e. a combination of scheduled and unscheduled services. Scheduled services, such as rail and sea, typically have the advantage of allowing fuel efficient transport by consolidation, while the use of unscheduled truck services offers increased flexibility and speed, at the cost of higher emissions, and increased load on the already congested road network. By improving the coordination in the network, the scheduled modes can achieve better transfer times, and thereby be made more competitive when considering the total transport time from origin to destination.

In this presentation, we examine the multimodal transport operations in a network surrounding the North Sea. We investigate whether the network allows for efficient modal transfers, and how the transport schedules can be improved to better support the overall network.

We have developed a cargo router, which finds the best way of routing a given cargo through the network, under the consideration of multiple objectives (price, duration, and CO_2 emission). It considers 20,000 actual scheduled transport opportunities in the region based on data from September 2012, and allows the combination of sea, rail and road modes. As expected, pure road transport often gives the fastest and most flexible route, while the scheduled modes are more competitive when other objectives are included in the calculation.

Next, we have implemented a large neighbourhood search-based algorithm to adjust the schedules, with the aim of improving the transfer opportunities in the network, and the synchronisation between modes. The schedule adjustment uses the route planner to evaluate the tested schedules. We then investigate the effects of adjusting the different modes, departures, and transfer opportunities

The project uses real-life data, with a network consisting of 47 cities in 14 countries, resulting in 75 potential transfer nodes, each having between 1 and 1200 monthly departures/arrivals, resulting in a total of approximately 17,000 monthly arrivals and departures.

A Survey on Algorithmic Approaches to the Generalized Vehicle Routing Problem

Petrică Pop*
Department of Mathematics and Computer Science, Technical University of Cluj-Napoca, North University Center of Baia Mare, Baia Mare, Romania, `petrica.pop@ubm.ro`

Andrei Horvat-Marc
Department of Mathematics and Computer Science, Technical University of Cluj-Napoca, North University Center of Baia Mare, Baia Mare, Romania, `a.horvatmarc@unbm.ro`

Corina Pop Sitar
Department of Economics, Technical University of Cluj-Napoca, North University Center of Baia Mare, Baia Mare, Romania, `sitarcorina@yahoo.com`

The generalized vehicle routing problem (GVRP) was introduced by Ghiani and Improta [2] and belongs to the class of generalized network design problems. Characteristic for this class of problems is the fact that it generalizes in a natural way many network design problems by considering a related problem on a clustered graph (i.e. graph where the nodes are replaced by node sets), where the original problem's feasibility constraints are expressed in terms of the clusters instead of individual nodes. Given a directed graph with the set of vertices partitioned into a given number of mutually exclusive nonempty subsets, called clusters, the generalized vehicle routing problem (GVRP) consists in finding a collection of simple circuits (each corresponding to a vehicle route) with minimum cost, defined as the sum of the costs of the arcs belonging to the circuits and such that the following constraints hold: each circuit visits the depot vertex, each cluster should be visited exactly once by a circuit, the entering and leaving nodes of each of the clusters should be the same and the sum of the demands of the visited vertices by a circuit does not exceed the capacity of the vehicle. In addition, we assume that each cluster can be satisfied via any of its nodes, there exist m identical vehicles and each vehicle may perform at most one route.

The problem has several applications: some extended naturally from the Vehicle Routing Problem (VRP) or the generalized traveling salesman problem (GTSP) and others specific to GVRP: the design of tandem configurations for automated guided vehicles, the design of routes visiting a number of customers situated in some islands of an archipelago, health-care logistics, urban waste collection problem, etc. It is known that the GVRP is NP-hard. Due to the complexity of the problem several heuristic approaches have been developed. The aim of this paper is to present an overview of the developed heuristic algorithms, including the adaptive large neighborhood search provided by Bektas et al. [1], the incremental tabu search heuristic described by Moccia et al. [3] and the hybrid heuristic algorithm obtained by combining a genetic algorithm (GA) with a local-global approach to the GVRP and a powerful local search procedure was developed by Pop et al. [4].

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Split-Based Metaheuristic for the Multitrip Cumulative Capacitated Vehicle Routing Problem

Juan Carlos Rivera*
ICD-LOSI, Troyes University of Technology (UTT), Troyes, France, `rivera_j@utt.fr`

H. Murat Afsar
ICD-LOSI, Troyes University of Technology (UTT), Troyes, France, `murat.afsar@utt.fr`

Christian Prins
ICD-LOSI, Troyes University of Technology (UTT), Troyes, France, `christian.prins@utt.fr`

A recent trend is to apply operations research techniques to facilitate logistic operations in disaster relief. An important logistic issue after a disaster is to determine the transportation routes for first aids, supplies, rescue personnel and equipment between supply points and a large number of destination nodes, geographically scattered over the disaster region. The arrival time of relief supplies at the affected communities clearly impacts the survival rate of the citizens and the amount of suffering.

In this sense, vehicle routing models can be considered for delivery in disaster context by using service-based functions to reflect the different priorities for delivering humanitarian aid. Campbell et al. [1] study and compare three different objective functions: minimize the total cost, minimize the maximum arrival time and minimize the average arrival time, where the two last ones are focused on routing relief.

A new version of the capacitated vehicle routing problem (CVRP) called the *multitrip cumulative capacitated vehicle routing problem* (mt-CCVRP) is studied. The mt-CCVRP is raised by the response phase of relief operations, in which a) the classical objective function (total time or distance traveled) becomes the sum of arrival times at required nodes and b) vehicles are allowed to perform multiple trips. This flexibility is necessary when the total demand exceeds the total capacity of the fleet of vehicles.

To the best of our knowledge, no published article has considered the mt-CCVRP. As Ngueveu et al. [2] showed, the special objective considered already complicates the moves in local search procedures for the cumulative CVRP, although each vehicle is limited to one trip in this problem. For instance, the cost of a sub-sequence of customers changes when it is inverted by a 2-opt move, contrary to the classical CVRP. The calculations are even more involved if multiple trips are allowed, since the cost of a multi-trip depends on the order of its trips.

In this work, a route first - cluster second metaheuristic for the mt-CCVRP is presented. This algorithm uses a giant tour of the n nodes which is translated in a set of R multitrips by an adapted split procedure (Prins [3]). A variable neighborhood descent (VND) algorithm, supported by a dominance rule, is applied to improve the solution. Results are compared with a multistart iterated local search procedure which works directly on mt-CCVRP solution space.

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A Branch-and-Price Algorithm for the Fixed Charge Transportation Problem Based on a New Mathematical Formulation

Roberto Roberti*
DEI, University of Bologna, Italy, `roberto.roberti6@unibo.it`

Enrico Bartolini
DISMI, University of Modena and Reggio Emilia, Italy, `enrico.bartolini@unimore.it`

Aristide Mingozzi
Department of Mathematics, University of Bologna, Italy, `aristide.mingozzi@unibo.it`

The Fixed-Charge Transportation Problem (FCTP) is defined on a bipartite network where a vertex partition corresponds to sources and the other vertex partition corresponds to sinks that require goods from the sources. The cost to send goods from a source to a sink is made up of a transportation cost proportional to the quantity delivered plus a fixed cost. The objective is to satisfy all sinks demands while minimizing the overall cost.

The FCTP was first formulated by [1]. The state-of-the-art exact method for the problem is owed to [2], who recently proposed a branch-and-cut algorithm that can solve 27 out of 30 instances with up to 15 source and 15 sinks within few minutes of computing time.

In this talk, we present a new integer programming formulation of the problem that involves an exponential set of variables for each source corresponding to all possible flow layouts that can be sent to the sinks. We show that the lower bound derived from the linear relaxation of the new formulation theoretically dominates the lower bound provided by the linear relaxation of the standard textbook formulation of the problem. We also describe different families of valid inequalities to tighten the linear relaxation of the new formulation, and a cut-and-column generation method to compute valid lower bounds. An optimal FCTP solution is then obtained with a branch-and-price algorithm that embeds these lower bounds.

Our computational results show that the lower bounds provided by the new formulation strictly dominate those provided by the standard formulation. The proposed exact algorithm based is compared against the exact method of [2], and the Integer Programming solver CPLEX (in its latest version 12.5). Our algorithm can solve all 30 instances considered by [2] within few seconds of computing time, and can solve instances with up to 70 sources and 70 sinks within a hour of computing time whereas CPLEX can solve only few instances involving up to 30 sources and 30 sinks.

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Sectors Design for Waste Collection Routing

Ana Maria Rodrigues*
INESC Tecnologia e Cincia Porto /Faculdade de Engenharia da Universidade do Porto /ISCAP - Instituto Politcnico do Porto, Portugal, `amr@inescporto.pt`

José Soeiro Ferreira
INESC Tecnologia e Cincia Porto /Faculdade de Engenharia da Universidade do Porto, Portugal, `jsoeiro@inescporto.pt`

For efficient planning of waste collection routing, large municipalities may be partitioned into convenient sectors. The case under consideration is to the municipality of Monção, in the north of Portugal. Waste collection involves more than 1600 containers over an area of 220 km^2 and a population of around 20,000 inhabitants. This is mostly a rural area where the population is distributed in small villages around the 33 boroughs centres that constitute the municipality. In most boroughs, waste collection is usually conducted 3 times a week. However, there are situations in which the same collection is done every day (except on Sundays).

The problem has the following general characteristics: there is a non-homogeneous fleet of vehicles starting and ending at a garage (depot); the vehicles are emptied at different places, which are landfills and transfer stations; there are different types of containers, from simple trash bags to more modern and large containers; the transfer stations may have limitations related to the restricted number of daily discharges. This last condition, which has never been described in the literature, led to the formulation of a new model: a Mixed Capacitated Arc Routing Problem with Limited Multi-Landfills.

The design of the sectors is inspired in Coulomb's Law, which establishes a relation of force (attractive or repulsive) between electrically charged points. Subsequently, each borough is represented by a point whose location coincides with the centroid given by the distribution of containers in that borough. Each point (borough) will establish relations of attraction/repulsion with the others (two by two), which will be proportional to the "charges" (represented here by the amounts of waste to be collected in both boroughs) and inversely proportional to their distance (initially a Euclidean distance).

The pair with maximum attraction will be chosen to integrate the same sector. The new sector will correspond to a new point on the segment that connects the centroids of the two chosen boroughs and a "charge" that corresponds to the sum of the "charges" of those two boroughs. The waste disposal facilities will also influence the process by introducing different attractions related to different receiving capacities. Throughout this process, it is possible to introduce additional information, such as geographical restrictions, past experiences or different frequencies of collection, which will make the attraction simpler or more difficult.

The solution procedure constitutes an iterative process and the numbers of sectors are reduced until a desired number is obtained. Convenient properties are defined and applied - Balance, Contiguity and Compactness - in order to produce good quality sectors.

Solving the Solomon Instances: The Importance of Branching Decisions

Stefan Ropke[*]
Department of Management Engineering, Technical University of Denmark, `ropke@dtu.dk`

In 1987 Marius M. Solomon published a paper [3] that proposed a several simple heuristics for the vehicle routing problem with time windows (VRPTW) and compared these heuristics on a newly constructed data set. The data set contained 56 instances with 100 customers each and has since become one of the most used and referenced benchmark sets in the operations research literature.

Researchers have attempted to solve the set of instances to optimality since its introduction and a steady increase in the number of solved instances can be observed over the years, culminating in [1] where 55 of the 56 instances were solved to optimality. This talk presents the first algorithm that is able to solve all 56 Solomon instances to optimality. The algorithm is based on the branch-and-price-and-cut framework.

The key to solving all Solomon instances lie in the branching decisions taken. A number of alternatives are proposed and compared experimentally, leading to a method involving strong branching that works very well overall. Using the same branching strategy on the capacitated vehicle routing problem is also successful as it leads to the solution of an instance containing 150 customers that was unsolved until last year.

Current research aims at solving VRPTW instances with 200 customers to optimality. These instances originate from [2] that introduced 60 such instances as well as many instances with an even higher customer count. Currently the proposed algorithm is able to solve a little more than a third of of the instances with 200 customers and it is believed that many of the unsolved instances will remain a challenge for the years to come.

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Column Generation for the Bi-Objective Multi-Vehicle Covering Tour Problem

Boadu Mensah Sarpong*
Univ de Toulouse, INSA, LAAS, F-31400 Toulouse, France, `bmsarpon@laas.fr`

Christian Artigues
Univ de Toulouse, LAAS, F-31400 Toulouse, France, `artigues@laas.fr`

Nicolas Jozefowiez
Univ de Toulouse, INSA, LAAS, F-31400 Toulouse, France, `njozefow@laas.fr`

We discuss the application of column generation in computing strong lower bounds for bi-objective integer programs (BOIP). A lower bound for a multi-objective integer problem is a set of points such that every nondominated solution of the problem is dominated by at least one of these points. Clearly, an ideal point satisfies the conditions of this definition, it is however usually a poor estimate of the nondominated set. Column generation can be used to compute a better lower bound for a BOIP by first converting the problem into a single objective one through an ε-constraint scalarization and then solving the resulting problem for different values of ε. Applying column generation in this way involves solving a class of similar subproblems for each member of the lower bound set. For this reason, different approaches in the application of column generation are presented. The interest is to find intelligent ways of solving some of the subproblems simultaneously rather than independently. The ideas presented are demonstrated through the study of the bi-objective multi-vehicle covering tour problem (BOMCTP) which is an extension of the covering tour problem (CTP) [1].

The BOMCTP is defined on an undirected graph made up of two sets of nodes and a set of edges. The problem consists in minimizing two contradictory objectives. The first objective is to minimiize the total distance of a set of routes constructed over a subset of the first set of nodes and the second objective is to minimize the maximum distance from a member of the second set of nodes to the closest member of the first set of nodes which is used by a route. Applications of the CTP and its variants, like the BOMCTP, include the design of bi-level transportation networks and the postbox location problem. A first formulation for the BOMCTP is given in [2] but because of its weak linear relaxation, the lower and upper bounds produced from it are poor.

In this presentation, we propose a new formulation for the BOMCTP and also compute strong lower and upper bounds by column generation. This new formulation uses a single-objective model to minimize the total length of the set of constructed routes whereas the second objective is managed through the definition of the column variables and when solving the subproblem. In this way, the possibility of weakening the formulation by explicitly introducing constraints on the second objective as it was done in the first formulation is avoided. In order to evaluate the quality of a lower bound for the BOMCTP, a corresponding upper bound based on the current columns in the model is computed is computed by a heuristic. Since the column generation method can take a considerable amount of time to converge, we also investigate the use of the different approaches as heuristics by stopping the generation process earlier and computing an upper bound.

Tests are run on randomly generated instances with similar characteristics to the ones presented in the literature and the results obtained clearly reveals the strength of the new model. A comparison of the different column generation approaches also show that an intelligent management of the columns in a multi-objective setting can yield significant speedups.

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The Electric Vehicle Routing Problem with Time Windows and Mixed Fleet

Michael Schneider*
Business Information Systems and Operations Research, University of Kaiserslautern, Germany,
`schneider@wiwi.uni-kl.de`

Dominik Goeke
Business Information Systems and Operations Research, University of Kaiserslautern, Germany,
`dominik.goeke@wiwi.uni-kl.de`

Rising energy costs and new regulations concerning the emission of greenhouse gases render electric commercial vehicles (ECVs) an alternative to conventional internal combustion commercial vehicles (ICCVs). Several companies are gradually introducing ECVs into their fleet, thus performing their last-mile deliveries with a mixed vehicle fleet. Compared to ICCVs, energy costs for operating ECVs are generally lower while labor costs may increase due to time spent for recharging activities along the routes (which may be necessary to overcome the range limitations of ECVs). Because energy and labor cost are among the main components of total operating costs (see, e.g., [1]), high-quality route planning with a mixed vehicle fleet has to consider the cost tradeoff between the two vehicle types.

We propose the Electric Vehicle Routing Problem with Time Windows and Mixed Fleet (E-VRPTWMF) to determine routes for the ECVs and ICCVs of a given mixed fleet with the objective of minimizing total costs. ECVs can be recharged at any of the available stations causing a recharging time that depends on the battery level on arrival at the station. We use realistic energy consumption functions of ECVs and ICCVs that integrate vehicle speed and load weight and their impact on the energy usage of both vehicle types and consequently the driving range of the ECVs [2,3]. To solve E-VRPTWMF, we develop a hybrid of Large Neighborhood Search and Tabu Search. We use a set of newly generated small problem instances to compare the performance of our solution method to a CPLEX implementation of the mathematical problem formulation. A set of large instances is used to demonstrate the effectiveness of the hybridization. To substantiate the performance of our method, we conduct further tests on benchmark instances of related problems from the literature.

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Synchronization in Vehicle Routing: Starting Time Coordination for Operations from Different Routes

Jörn Schönberger[*]
Chair of Logistics, University of Bremen, Bremen, 28359 Bremen, Germany, `jsb@uni-bremen.de`

Scheduling comprises the determination of starting times of operations. In the context of vehicle routing, scheduling addresses the determination of arrival times of vehicles at (customer) locations and the determination of starting times of loading or unloading operations. A scheduling procedure is invoked after the compilation of routes has been completed. This scheduling procedures is applied to each of the determined routes according to a specified route sequence. The earliest possible arriving times as well as the earliest allowed starting times of loading respectively unloading operation are calculated recursively along the determined routes (sequential scheduling).

The consideration of time windows for the starting of operations makes the scheduling more complicated and complex but the sequential scheduling technique is still applied. In the here reported research we investigate a vehicle routing scenario in which two different vehicles fulfill split requests together. The starting times determined for the operations associated with the two vehicles visiting a customer site must be coordinated so that the difference of the starting times of loading or unloading operations of the two involved vehicles does not exceed a given allowed difference. Such an coordination is called *operations synchronization*.

Obviously, sequential scheduling is hardly capable to determine synchronized (e.g. coordinated) operation starting times in routes of different vehicles. It becomes necessary to check and compare operation starting times across the routes of the two involved vehicles. We propose to enrich the sequential scheduling procedure by the check if an operation associated with a split request has already been scheduled for another vehicle and this starting time is considered for the determination of the operation starting time associated with the second involved vehicle. The resulting procedure is integrated in a genetic algorithm framework for solving instances of a vehicle routing problem with operations synchronization. Initial computational experiments demonstrate that the incorporation of the enriched sequential scheduling procedure is able to guarantee the coordination of operation starting times across two routes if the portion of split requests is small (less than 60%). However, if the portion of split requests in the portfolio is above 60% then the sole application of the enriched sequential scheduling procedure fails to meet the maximal allowed operation starting time difference for a subset of the request portfolio.

One approach to improve the performance of the enriched sequential scheduling paradigm is to identify routes that contain critical operations and to schedule such routes prior to other routes. An operation is critical if it belongs to a split request. It becomes necessary, to identify an appropriate permutation of the route set to determine the sequence in which the routes are scheduled. We propose several strategies for determining such a permutation (random permutation, number of incorporated operations in a route, number of critical operations in a route, etc.) and report about results from computation experiments. Furthermore, we compare the achieved results with a quasi-parallel schedule procedure that determines the operation starting times of a split request for both vehicles simultaneously.

Modern Shortest Path Algorithms in Practice

Frank Schulz*
PTV Group, Haid-und-Neu-Str. 15, 76131, Germany, `frank.schulz@ptvgroup.com`

In the last few years there has been a lot of research on routing algorithms solving the shortest path problem in road networks. With a certain amount of preprocessing the new methods allow to answer shortest path queries by several orders of magnitude faster than Dijkstra's algorithm.

In addition to solving a plain shortest path problem in a simple road graph (i.e., nodes are crossings and edges are road segments with travel time as cost), a routing algorithm for practical route or tour planning has to fulfill further requirements. For example, some turns are not allowed or, more general, turn costs have to be applied. Another crucial point is the optimization goal for the routes: multiple criteria such as distance, travel time, or toll price are involved, and some of the criteria are even time-dependent.

The presentation is structured as follows: First, a short overview of recent developments is given (see [1] for a survey of the developments up to 2009). Then, two examples demonstrate how the new techniques can be used in practice to generate input data for solving vehicle routing problems and multi-modal transportation problems. The examples are based on the Contraction Hierarchies technique [3].

The first example is the efficient calculation of origin-destination matrices [3,4] as input for vehicle routing problem. For each pair of locations (e.g., depots or customers) that occur in a vehicle routing problem information about the route connecting these two locations is required. The most common data are the distance and travel time of the route. But also data like the toll price or CO_2 emissions are of increasing interest for rich vehicle routing problems.

Another example from ongoing research projects deals with multi-modal transportation. Several containers have to be transported from some location to another location, and multiple modes of transportation like truck, ship, or train are possible. Initially we generate for these transport orders a candidate set of reasonable multi-modal routes, taking into account multiple optimization criteria. The use of the Contraction Hierarchies technique allows to calculate the multi-modal routes very fast (a similar approach for public transportation is described in [2]). Based on these multi-modal routes we create a network with capacities and solve a multi-commodity flow problem on this network. The crucial advantage of this approach is the size of the network – without the candidates for the routes the network would be far too large.

These examples show that modern shortest path algorithms are of vital importance for vehicle routing and logistics optimization. At PTV we have successfully integrated some of the new techniques into our software products and contribute to the ongoing research.

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Clustering Customers in the VRPTW with Multiple Service Workers

Gerald Senarclens de Grancy*
Institute of Production and Operations Management, School of Social and Economic Sciences, University of Graz, Austria, `gerald.senarclens-de-grancy@uni-graz.at`

Marc Reimann
Institute of Production and Operations Management, School of Social and Economic Sciences, University of Graz, Austria, `marc.reimann@uni-graz.at`

In ever growing urban areas, space becomes increasingly valuable. Hence, even smaller stores servicing local customers may not be able to provide dedicated parking spaces. This lack of space to park, even though encouraging alternative means of transport, constitutes a problem for the stores' suppliers. Virtually all routing applications as well as academic papers implicitly assume that it is possible to stop at the desired destination. However, this assumption doesn't hold if there are no parking spaces available that could fit a delivery truck.

Given these circumstances, distribution planning requires clustering nearby customers around known parking locations. Deliveries from each parking location to its assigned customers occur by foot. These lead to long service times at each of the clusters. However, long service times in conjunction with time windows can lead to inefficient routes as nearby customer clusters with overlapping service times may not be connected. As a consequence, assigning additional service workers to each vehicle is a strategy to reduce service times and hence permit more efficient routes. The trade-off between paying additional workers to reduce costs for vehicles and driving creates a new decision problem called the vehicle routing problem with time windows and multiple service workers (VRPTWMS).

Prior work of [1] assumes that the customer clusters are given input data. As this does not hold in reality, there is need for an algorithm combining customers to clusters with a parking space in each of them. To tackle this issue, we identify relevant characteristics, parameters and issues when combining customers with time windows. We then introduce and systematically evaluate combined clustering and routing strategies for obtaining high quality solutions to the VRPTWMS.

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Efficient Local Search for a Capacitated Vehicle Routing Problem with Due Dates and Batch-Availability Constraints

Benjamin C. Shelbourne*
School of Mathematics, University of Southampton, Highfield, Southampton, SO17 1BJ,
`bcs1g11@soton.ac.uk`

Chris N. Potts
School of Mathematics, University of Southampton, `c.n.potts@soton.ac.uk`

Maria Battarra
School of Mathematics, University of Southampton, `m.battarra@soton.ac.uk`

In the Vehicle Routing and Scheduling literature, integrated production and distribution scheduling problems have been gaining interest (see [1]). A novel extention of the classical Capacitated Vehicle Routing Problem arises as a sub-problem of this direction of research. This problem, which we will call the Vehicle Routing Problem with Due Dates and Batch-availability Constraints (VRPDDBC), includes due dates on customer service and release dates on customer demand at the depot, leading to batch-availability constraints on vehicle departure. Considering the practical importance of this problem, to our knowledge this problem has not been addressed in the literature, and therefore we will give an introduction and formal definition of the problem.

In our study, we seek to explore the practical trade-off between distribution cost and customer service level, measured as tardiness to customer service. By allowing tardiness in a traditional total weighted tardiness scheduling approach, we permit the necessary prioritisation of customers in the situations where no feasible solution exists without tardiness, or when tardiness is acceptable if relevant savings on the distribution cost can be achieved. We describe a number of different problem settings to examine this, prioritising the objectives differently.

To solve these $\mathcal{NP}$-hard problems, we have decided to experiment with a number of different Local Search neighbourhood operators, to evaluate their performances. An efficient move evaluation procedure to reduce the time complexity of neighbourhood exploration is described, based on the recently popularised evaluation by 'concatenation' [2]. Some experimentation with dynamic infeasibility penalties on the load constraints is made, in the spirit of [3]. We also explore some static and dynamic neighbourhood pruning strategies, based on granularity [4] measured in both time and distance, and lower bounding respectively. To gain computational experience for this problem, we present an adaptation of the set of [5] instances for the Vehicle Routing Problem with Time Windows, and extensive computational results.

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Optimal Toll Enforcement — An Integration of Vehicle Routing and Duty Rostering

Elmar Swarat*
Optimization, Zuse Institute Berlin, Berlin, Germany, `swarat@zib.de`
Ralf Borndörfer
Optimization, Zuse Institute Berlin, Berlin, Germany, `borndoerfer@zib.de`
Guillaume Sagnol
Optimization, Zuse Institute Berlin, Berlin, Germany, `sagnol@zib.de`

We present an integrated vehicle routing and crew rostering model to plan the tours of toll enforcement inspectors on German motorways, where trucks with more than 12 tonnes vehicle weight have to pay a distance-based toll. The enforcement of the toll is either done by 300 stationary *control gantries* or by tours of about 250 mobile control teams consisting of one or two inspectors through the motorway network. Our challenge is to solve the VRP of the mobile teams. An important requirement is that the control should cover the complete network. Hence, we use covering constraints for the sections. Our main objective is that the control is planned in order to maximize the number of controlled vehicles.

Classical VRPs result in a set of tours. In a subsequent step drivers are assigned to the tours. The feasibility of crew assignments is not part of algorithms to solve the classical models. But in the toll control setting there are only a few drivers that can perform a planned tour since each tour must start and end at the home depot of its associated team. Thus, sequential approaches to plan the tours independently of the crews tend to fail. If we assign a crew to each tour, it must fit within a feasible crew roster, respecting all legal rules over a time horizon of several weeks, e.g., minimum rest times or maximal amounts of consecutive working days. Hence, a personalized duty roster planning must be used in our model. Therefore, we developed a novel integrated approach, that leads to a new type of vehicle routing problems.

We have called our optimization problem *Toll Enforcement Problem (TEP)*, and it is introduced in [1]. To determine the tours we use a time-expanded graph model. It is based on a division of the network into small subparts, called sections, and transfer arcs between sections. Then the size of the resulting space-time graph D depends on the chosen time discretization Δ, e.g., two or four hours. The *Tour Planning Problem (TPP)* correlates then to a Multi-Commodity Flow Problem in D. It is formulated by an IP based on path variables. Since each control team can only control some local sections, it is still possible to generate all paths by a simple enumeration.

The crew scheduling part of the model is called the *Inspector Rostering Problem (IRP)*. We formulate the IRP again as a Multi-Commodity Flow Problem in a directed graph $\tilde{D} = (\tilde{V}, \tilde{A})$. The nodes $\tilde{v} \in \tilde{V}$ represent duties as a pair of day and duty type. The arcs $(u, \tilde{v}) \in \tilde{A}$ model a feasible sequence of two duties according to legal rules. A feasible roster corresponds then to a path in D. This problem is again modeled by an IP, but based on arc variables. Both IPs are then connected by coupling constraints. Since most of the model complexity has its origin in satisfying the legal requirements of the duty rosters, we will have a focus on that in our presentation. We will show that by our modeling power it is still possible to solve real-world instances with an exact IP approach by CPLEX within a few hours almost to optimality. In our opinion this exemplary approach on toll enforcement can also be used in other inspection tasks, like ticket inspection or police patrols. An even in classical VRP approaches it might be important to consider the availability of crews while planning the tours.

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The Time-Dependent Vehicle Routing Problem with Soft Time Windows and Stochastic Travel Times

Duygu Taş[*]
School of Industrial Engineering and Innovation Sciences, Eindhoven University of Technology, P.O. Box 513, 5600 MB, Eindhoven, The Netherlands, `d.tas@tue.nl`

Nico Dellaert, Tom van Woensel, Ton de Kok
School of Industrial Engineering and Innovation Sciences, Eindhoven University of Technology, P.O. Box 513, 5600 MB, Eindhoven, The Netherlands, `n.p.dellaert@tue.nl`, `t.v.woensel@tue.nl`, `a.g.d.kok@tue.nl`

In real-life applications, travel times are time-dependent since speeds of vehicles vary throughout the day. We do not have a constant speed over the entire scheduling horizon due to the traffic network which has different levels of congestion depending on the time of the day. In addition, travel times on each individual arc are stochastic. Routing customers with respect to a deterministic and static schedule is a strong assumption for real-life environment, leading to inefficient operations. To have more realistic representations of real-life problems, several versions of the Vehicle Routing Problem (VRP) have been addressed, such as stochastic routing problems and time-dependent routing problems.

In this paper, we focus on the VRP where we have both time-dependent and stochastic travel times. In our problem setting, customers have time windows which are the constraints given for the time of service and relaxed to allow early and late arrivals (soft time windows). The aim is to minimize the sum of transportation costs and service costs. Transportation costs comprise three main elements which are the total distance traveled, the number of vehicles used and the total expected overtime of the drivers. Service costs are the penalty costs paid by the carrier company due to early and late services. To obtain both efficiency and reliability at the operational level, we use the mathematical model proposed in Taş et al. [1]. These authors study a VRP with stochastic (time-independent) travel times and soft time windows, and propose a new solution procedure based on Tabu Search. For our problem, we adjust both the model and the solution approach given in [1] with respect to time-dependency. In addition, we implement an Adaptive Large Neighborhood Search procedure similar to Ropke and Pisinger [2]. First, two heuristics are applied to the case assuming no service times at the customers. This exclusion enables us to calculate the exact values of the mean and the variance of arrival times. Approximations are needed in the second case where we include service times.

We conduct extensive analyses on the numerical results: (i) solutions of two heuristics are compared with respect to each other, (ii) solutions of two heuristics are compared with the ones obtained in Taş et al. [1] for a VRP with soft time windows and stochastic travel times (time-independent), (iii) solutions of two heuristics are compared with the optimal/best-known solutions obtained for the VRP with hard Time Windows (the classical VRPTW) where travel times are deterministic (time-independent).

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Bound Sets for the Biobjective Team Orienteering Problem with Time Windows

Fabien Tricoire*
Department of Business Administration, University of Vienna, Austria,
`fabien.tricoire@univie.ac.at`

Sophie N. Parragh
Department of Business Administration, University of Vienna, Austria,
`sophie.parragh@univie.ac.at`

When solving orienteering problems, a fleet of vehicles is used to visit a set of *control points*. To each control point i is associated a profit p_i. Due to operational constraints it is impossible to visit all control points; the objective is to maximize the total profit. In the team orienteering problem with time windows (TOPTW), these constraints are the size of the fleet and hard time windows at control points. We consider a biobjective extension of the TOPTW, which we call the BITOPTW, where the second objective is the minimization of total travel costs. We use the *Pareto* approach, meaning that each objective is equally important and that the decision maker's preference between these two objectives is unknown. Therefore the output of an optimization algorithm for the BITOPTW is a set of non-dominated solutions.

Although the two objectives are maximization of total profit and minimization of total cost, in the following we consider, without loss of generality, a biobjective minimization problem. Transforming the BITOPTW to a biobjective minimization problem can be achieved by multiplying all p_i values by -1. Similarly to [1], we consider *bound sets*. Lower bound sets are obtained by solving exactly a relaxation of the BITOPTW, while upper bound sets are produced by heuristic means.

In order to produce a valid lower bound set, we formulate the BITOPTW as a set packing problem, where each element (control point) can be covered at most once by the selected subsets (routes). The linear relaxation of this model is solved using column generation. The subproblem is an elementary shortest path problem with resource constraints, which we solve using dynamic programming with an algorithm similar to the one described by [2]. To produce a valid lower bound set, we solve a succession of single-objective versions of the BITOPTW, using weighted-sum aggregations of the two objectives. We prove that the set of aggregation functions that we consider is sufficient to generate the convex hull of the Pareto-optimal set in the objective space for the relaxed problem. Therefore the obtained set is a valid lower bound set for the BITOPTW.

The upper bound set is produced using multi-directional search (MDLS), a metaheuristic for multi-objective optimization introduced by [3]. MDLS requires single-objective local search for each objective; for that purpose we use large neighborhood search (see [4]), and implement a small set of *destroy* and *repair* operators.

We provide experimental data regarding the gap between lower and upper bound sets. Since we are comparing continuous sets with discrete sets, specific performance indicators are developed.

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Anticipatory Optimization for Routing in the Euclidean Plane

Marlin W. Ulmer*
Business Information Systems, Technische Universitt Braunschweig, Braunschweig, Germany,
`m.ulmer@tu-brauschweig.de`

Dirk C. Mattfeld
Business Information Systems, Technische Universitt Braunschweig, Braunschweig, Germany,
`d.mattfeld@tu-braunschweig.de`

Today logistic service providers face highly dynamic challenges. Customers can request service at any point of time and at any location within the served region while expecting immediate service. Also, technical developments and the analysis of historical data allow more detailed and dynamic routing and decision making, which leads to more satisfying solutions [1]. The high amount of data, however, longs for an adequate representation in order to improve routing decisions.

We compare two different approaches of modeling customer requests for an exemplary problem. In the representative approach (REP) occurring requests are mapped to a discrete set of representatives, defined in advance. In the Euclidean Plane approach (EP) customer locations are modeled as spatial and temporal random variables.

The trade-off between data and model complexity is evident. REP allows the application of efficient graph theoretical algorithms, but may insufficiently model dynamic spatiotemporal customer requests and may lead to inefficient routing and planning decisions. To achieve satisfying solutions data must be modified sophistically for the REP. EP, however, considers the original data and leads to a more realistic problem representation, but requires the application of more complex algorithms for anticipation of future customer requests.

Therefore, we adjust methods of approximate dynamic programming (ADP) to the EP model. Because customer requests can occur at any place in the Euclidean Plane this results in an infinite number of possible request constellations. So, the state space has to be modeled in a sophisticated and efficient way to achieve high-quality solutions [2].

We compare both REP and EP by means of a dynamic and stochastic pickup problem, in which a single vehicle serves occurring customer requests regarding a time limit. We examine the solutions of both a myopic strategy and ADP. In the myopic approach EP outperforms REP significantly regarding the number of served customers. Additionally we show that anticipation in the EP is possible with reasonable computational effort and leads to clear improvements compared to REP.

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Feasible Insertion Genetic Algorithm for VRP with Constraints

Gintaras Vaira*
Vilnius University, Institute of Mathematics and Informatics, Akademijos St. 4, LT 08663, Vilnius, Lithuania, `gintaras@vaira.net`

Olga Kurasova
Vilnius University, Institute of Mathematics and Informatics, Akademijos St. 4, LT 08663, Vilnius, Lithuania, `olga.kurasova@mii.vu.lt`

Vehicle routing problem (VRP) is well known combinatorial problem that attracts researchers to experiment with existing and newly created optimization algorithms. Traditionally VRP is defined as routing problem with single depot, set of customers, and multiple vehicles. Among traditional definitions in literature we can find different kinds of VRP problems that are grouped by specific constraints. Well known VRP constrained problems are VRP with limited capacity (CVRP), with time windows (VRPTW), with multiple depots (MDVRP), with pick-up and delivery (VRPPD), etc. [1]. For mentioned problems many researches can be found from exact algorithms to different heuristic approaches. In this research, we are dealing with one of the meta-heuristic approaches; genetic algorithms (GA) that iterates over generations of individuals, creates new offspring in each iteration by performing stochastic transitions on previous generation of individuals and finds and emits individuals with the best fitness value. In hardly constrained problems the set of feasible solutions within a problem is significantly smaller than a full set of solutions and the search space contains a high number of infeasible solutions [2]. Stochastic GA characteristic permits a generation of new solution in the whole search space including the infeasible area. In this research we propose a genetic algorithm scheme that is based on insertion heuristics that belong to solution construction algorithms. Solomon heuristics are well known approaches for VRPTW problem where node with the best value is searched for insertion into the constructed solution [3]. Instead of searching for the best node, the proposed scheme deals with random selection of the node. Then the selected node is inserted into the best arc within current solution, where the best arc is found from all current arcs in the solution by calculating objective functions defined from constraints and selecting a minimal one. The random node selection preserves stochastic characteristics of the genetic algorithm. The aim of the process of the random node selection and insertion into the best arc is to generate solutions in the feasible area. Infeasibility is still allowed in proposed scheme because the random mechanism can build infeasible initial solutions in hard constrained problem. In this research we are dealing with GA operators with incorporated random insertion process. For selected scheme crossover and mutation operators are defined, where crossover operator analyses pairs of individuals, identifies parts in solutions that should be reconstructed and reinserts nodes by described feasible insertion mechanism; and mutation process analyses a single solution, and extracts subset of nodes to reinsert them back. Research results are compared to solutions of other widely used approaches for constrained VRP.

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Branch and Price for the Pollution-Routing Problem

Tom Van Woensel*
School of Industrial Engineering, Eindhoven University of Technology, 5600MB Eindhoven, The Netherlands, `t.v.woensel@tue.nl`

Emrah Demir
School of Industrial Engineering, Eindhoven University of Technology, 5600MB Eindhoven, The Netherlands, `e.demir@tue.nl`

Said Dabia
School of Industrial Engineering, Eindhoven University of Technology, 5600MB Eindhoven, The Netherlands, `s.dabia@tue.nl`

The transportation sector, and in particular road freight transport, is a significant emitter of carbon dioxide equivalent (CO_2e) emissions, which measure how much global warming a given type and amount of greenhouse gas may cause, using the functionally equivalent amount or concentration of CO_2 as the reference.

The pollution-routing problem (PRP) is an extension of classical vehicle routing problem with time windows (VRPTW) and introduced by [1] and further studied by [2]. The PRP consists of routing a number of vehicles to serve a set of customers and deciding on their speed on each route. In the context of the PRP, two important objectives should be taken into account, namely minimization of fuel consumption and the total driving time. The amount of fuel consumption depends on the energy required to move a vehicle from one point to another. Another important issue in road transportation is time management. In freight transport terminology, time is money and it is essential for firms to perform timely deliveries in order to establish and keep a good reputation.

A mathematical model of the PRP is non-linear in nature, although it can be linearized and represented as a mixed integer linear programming formulation. Solving medium scale instances to optimally, however, still remains a challenge using such a linearized formulation, which calls for efficient exact algorithms to solve the PRP.

In this study, we propose an exact solution for the PRP based on a branch-and-price algorithm. The aim is to determine the set of routes that minimizes the sum of fuel consumption and total driving time. Furthermore, the speed on each route must be decided on. The master problem is a classical set partitioning problem, and a speed-dependant elementary shortest path problem with resource constraints is studied as the pricing problem. Considering speed as a decision variable significantly complicates the pricing problem as the dominance test becomes harder. We solve the pricing problem by means of a tailored labeling algorithm. Moreover, we introduce a tailored dominance set to discard more labels in the label setting algorithm. Computational results are presented on realistic instances to show the performance of the proposed algorithm.

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From VRP Research Toward GIS Prototype

Sacha Varone[*]
Haute École de Gestion de Genève, Switzerland, `sacha.varone@hesge.ch`

Iliya Markov
Haute École de Gestion de Genève, Switzerland, `iliya.markov@hesge.ch`

VRP real applications need not only to use efficient algorithms, but also a visual representation based on maps, if one wishes either to sell it as a product or at least to receive positive feedback from users. Research on VRP-like problems often starts from a well-defined metric. Benchmark data set accessible to the research community should be used to assess the performance of different methods. Unfortunately, the majority of the papers in that field are based on randomly generated problems. Although some benchmarks based on real data exist, it is preferable for enterprise funding research to show results based on and visualised by customised maps.

Real cases of VRP need a Geographic Information System (GIS). First, GIS is used to provide shortest distances between the selected customers to be served; second, GIS allows to visualise the results. The importance of linking transport problems and GIS is recognised by the American Association of State Highway and Transportation Officials which call it GIS for transportation (GIS-T).

In this talk, we present an explanation on how to transform a VRP research into a GIS integrated prototype. We first specify the process to reach this goal, then we mention the different tools needed to build such a GIS prototype. Several questions need to be answered: what choice of data map? Where to look for tools? What is already (freely) available?

We illustrate our presentation with our own experience on a real case pick-up and delivery container vehicle routing problem: a set of containers for waste collection has to be managed. A container needs to be cleaned, or only controlled, moved to another location or replaced. Some moves have a higher priority. A single vehicle with a limited capacity can be used to move the containers and several depots exist. Prior to solving this problem, we have defined the framework and the elements of a working prototype. The goal is as a first step to get a visual representation of the locations given by their longitude and latitude, to compute the distance matrix using shortest paths, to use a basic VRP algorithm and finally to show the resulting routes on a map.

On Unified Methods for Multi-Attribute VRPs, Route Evaluation Operators and Large Neighborhoods

Thibaut Vidal*
CIRRELT, Département d'informatique et de recherche opérationnelle, Université de Montréal, Canada. ICD-LOSI, Université de Technologie de Troyes, France, `thibaut.vidal@cirrelt.ca`

Teodor Gabriel Crainic
CIRRELT, Département de management et technologie, École des sciences de la gestion, UQAM, Montréal, Canada, `TeodorGabriel.Crainic@cirrelt.ca`

Michel Gendreau
CIRRELT, Département de mathématiques et génie industriel, École Polytechnique, Montréal, Canada, `Michel.Gendreau@cirrelt.ca`

Christian Prins
ICD-LOSI, Université de Technologie de Troyes, `Christian.Prins@utt.fr`

Practical Vehicle Routing Problem (VRP) applications bring forth additional constraints, objectives and decisions, which we call attributes, complementing the classic problem formulations and leading to a wide variety of Multi-Attribute VRP (MAVRP). To address such problems, Vidal et al. [1] proposed a modular heuristic resolution framework strongly anchored to the MAVRPs structure, along with a Unified Hybrid Genetic Search (UHGS). This metaheuristic relies on unified problem-independent methods: unified local search, genetic operators, Split algorithm and diversity management. Problem-specific strategies are restricted to a few modular components which allow changing assignment choices (e.g. customers to depots or to days), enumerating sequencing alternatives, and evaluating routes. These components are automatically adapted to the attributes of the problem at hand. Computational experiments demonstrate the groundbreaking performance of UHGS which, with a single implementation, parameter setting and termination criterion, matches or outperforms all current problem-tailored methods, issued from more than 180 articles, on 26 vehicle routing variants and 39 benchmark sets.

In this work, we introduce new advanced route evaluation modules based on bi-directional dynamic programming and concatenation concepts which contribute to address an even wider range of difficult MAVRP. Our route evaluations methods go far beyond a classic objective computation. They allow for an efficient large neighborhood search with compound sequencing and attribute-related decisions, e.g. assignment to depots, to vehicle types, route rotations, customer selection in a generalized or clustered VRP, selection of customers in a prize-collecting setting, and other decisions for arc routing problems. Our computational experiments demonstrate the contribution of the new compound neighborhoods to the search performance, and new best solutions for prominent VRP variants are obtained. Furthermore, attribute-specific decisions, which make the problem more intricate, are no longer explicitly addressed in the solution structure and the heuristic method but simply relegated as a component of the route evaluations. A higher level of abstraction on problem solving is achieved, and very few critical problem-specific elements are identified.

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Territory-Based Vehicle Routing in the Presence of Time Window Constraints

Daniele Vigo*
DEI - Univeristy of Bologna, Italy, `daniele.vigo@unibo.it`

Michael Schneider
BISOR, Technical University Kaiserslautern, Germany, `schneider@wiwi.uni-kl.de`

Andreas Stenger
Lufthansa, Hamburg, Germany, `andistenger@gmail.com`

Fabian Schwann
BISOR, Technical University Kaiserslautern, Germany, `schwann@wiwi.uni-kl.de`

Territory-based routing approaches (TBRAs) are commonly used to achieve high service consistency, e.g., in the small package shipping industry, but their drawback is a decline in routing flexibility. Consequently, a high percentage of time-definite deliveries, as common in the small package shipping sector, should have a significant negative effect on the solution quality of TBRAs.

If time windows are considered, routing flexibility is not only needed to achieve distance-efficient route configurations but also to fulfill the time requirements of customer deliveries. Thus, the value of routing flexibility should increase, which is likely to have a negative effect on the solution quality of TBRAs. However, to the best of our knowledge, no study exists on the magnitude of this effect and the factors that influence it.

The central questions studied in this work are:

- How well do TBRAs perform in the presence of time window requirements? More precisely, we study 1) to what extent the goals of feasible and distance-efficient routes can be achieved with a TBRA under time window constraints, and 2) how well the implicit realization of consistency benefits (without directly optimizing consistency in any way but only due to the restriction to STs) is achieved.
- How strong is the influence of factors such as the size of the STs, the customer distribution, the tightness, frequency and spatial distribution of time windows or the variance of the daily demand on this performance?

To address these questions, we develop a TBRA to solve a series of Vehicle Routing Problems with Time Windows (VRPTW) that are linked by a common customer base set. On every day of a given time horizon, a random subset of these customers requires service. This corresponds to the practical problem faced by many SPS companies. The proposed TBRA is a two-phase method called *Modular Territory Routing* (MTR) that first divides the delivery area into STs based on historical, spatial and time window related information. In the second phase, it defines the daily routing based on these STs. The aim of our approach is to provide a performance that is good enough to achieve meaningful results in the numerical studies addressing the above questions while maintaining (relative) simplicity.

We find that the consideration of geographical aspects in the districting is paramount for generating high-quality territories, while explicitly incorporating time window characteristics and historical demand data do not lead to a perceptible improvement of the solution quality. Moreover, the efficiency and feasibility forfeits of our TBRA in comparison to daily route reoptimization (RR) are larger if time windows are present. However, significantly higher consistency improvements compared to RR are achieved for time-constrained problems. This is due to the fact that RR solutions to time-definite problems exhibit lower consistency and thus a higher potential for improvement by using a TBRA, which constitutes an important insight for practitioners.

A Pickup and Delivery Problem for Ridesharing Considering Congestion

Xiaoqing Wang*
Department of Industrial Engineering, University of Southern California, Los Angeles CA, USA., `xiaoqinw@usc.edu`

Maged Dessouky
Department of Industrial & Systems Engineering, Department of Industrial & Systems Engineering, Los Angeles CA 90007, USA., `maged@usc.edu`

Fernando Ordonez
Department of Industrial Engineering, Universidad de Chile, Department of Industrial Engineering, Santiago, Chile, `fordon@dii.uchile.cl`

Ridesharing, or carpooling, occurs when individuals share a vehicle for a trip. This practice reduces travel cost and congestion but requires the coordination of itineraries and schedules among travellers. In this talk, we present an approach to create itineraries for the formation of ridesharing that takes into consideration their unique characteristics. For example, because of the existence of toll roads and the availability of High Occupancy Vehicle (HOV) lanes, ridesharing could provide cost reduction and time savings under congestion. We consider a vehicle pickup and delivery problem with the object of minimizing the total travel cost and the passenger travel time considering the congestion. A 0-1 integer programming model is formulated to solve the problem optimally. And a heuristic based on an insertion procedure and then a tabu improvement phase is also developed to solve the problem in an efficient way. Finally, a waiting strategy for the vehicles is applied with the purpose to satisfy more requests at less cost and time for the dynamic real-time case.

Towards a General Meta-Heuristic Optimiser for Vehicle Routing: Experiments on Six VRP Types

Philip Welch*
Computer Science, Aston University, UK, B4 7ET, `research@pgwelch.info`
Anikó Ekárt
Computer Science, Aston University, UK, B4 7ET, `a.ekart@aston.ac.uk`

We present a simulation-based model of vehicle routing problems (VRPs) conceptually half way between a rich model and a domain specific language. The aim is to allow a user to define and optimise a broad range of problems without needing the high-level mathematical skill set required by linear or constraint programming. We value ease-of-use and model flexibility above pure solution quality. The foundation of this flexibility is the solution evaluation method: we treat each route as a separate discrete event simulation modelled using a directed acyclic graph. Each stop is one or more events. The user supplies functions which define the simulation logic, constraints and costs. User defined constraints can also be placed on the assignment and relative positions of stops. Solution modifications are evaluated relatively efficiently by propagating them on the graph and recalculating values that change.

The optimiser uses local improvement heuristics (e.g. swap, two-opt) together with a novel move heuristic for assignment and relative position constraints between stops which allows many problems to be addressed. These are embedded within a controlling meta-heuristic with a similar design to the hybrid genetic algorithm with diversity management used in the UHGS solver [1]. UHGS can optimise a range of problems based on a library of problem-specific route evaluation operators. We introduce more flexibility by allowing the user to define these operators by supplying arbitrary functions. The hardcoded UHGS operators will be quicker than our own, but new problems will only be supported if they can be defined using the existing operators. As users define our operators this restriction does not apply to our model.

Our flexible approach can be applied on a wider range of problems than normal for a single study. We tested benchmarks for the 2-echelon VRP (2E-VRP), capacitated arc routing problem (CARP), multi-trip VRP (MTVRP), periodic VRP (PVRP), pickup-deliver VRP with time windows (PDVRPTW) and VRP with time windows (VRPTW). Of these, only the PVRP and VRPTW are listed as supported by UHGS [1]. Dependent on the problem, we tested instances with a maximum of 100 to 200 nodes and performed a single run per instance with maximum 30 minutes runtime. The 2E-VRP generated both our best and worst results. For the 50 node instances we found only a 0.56% mean gap from the best known solutions with new best solutions found for 7/69 instances; conversely the 100 node instances had a 7% mean gap. For CARP, PDVRPTW, PVRP and VRPTW under 200 nodes we found a small mean gap of between 0.5%-3.0%[3]. Solution quality degraded approaching 200 nodes with poor results for the 200 node PDVRPTW and VRPTW. For the MTVRP we tested the CMT Taillard instances and found feasible solutions for 68/92 instances with poor performance mostly restricted to the large 199 node ones; other authors using algorithms specifically tailored for the MTVRP found between 66 and 87 feasible. Our feasible solutions had a 1.36% gap from best known solutions.

Our results demonstrate that although work is required to extend the model to larger instances, below 100 to 200 nodes we can generate solutions competitive with the top-performing algorithms, with only a percent or so gap from best known solutions. Moreover, the vast majority of the top algorithms used meta-heuristics with local improvement heuristics tailored to a narrower range of problems than our own; they would not have been able to optimise all the problems we can. The almost exclusive use of (meta) heuristic approaches by other authors suggests that our 'competitive' problem size range includes problems too large for non-tailored mathematical programming techniques.

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[3] PDVRPT and VRPTW figures quoted for 53/56 and 48/56 instances where we equalled best known number of vehicles.

Formulations for the Station Location Problem for Electric Vehicles

Min Wen*
DTU Transport, Technical University of Denmark, Copenhagen, `mw@transport.dtu.dk`
Gilbert Laporte
Canada Research Chair in Distribution Management and CIRRELT, HEC Montréal, Canada, `gilbert.laporte@cirrelt.ca`
Oli B.G. Madsen
DTU Transport, Technical University of Denmark, Copenhagen, `ogm@transport.dtu.dk`
Anders V. Nørrelund
DTU Transport, Technical University of Denmark, Copenhagen, `ann@transport.dtu.dk`
Allan Olsen
DTU Transport, Technical University of Denmark, Copenhagen, `aol@transport.dtu.dk`

During the past few decades, environmental concerns have generated a renewed interest in electrical vehicles. The current yearly worldwide sales of fully electric vehicles now stand at around 20,000 units. The market is expected to grow to 750,000 units in 2020 in the European Union (EU) alone. The major advantage of electrical vehicles is that they are environment-friendly and produce almost no air pollutants. However, electrical vehicles have a limited driving range due to the low density of their batteries. It is therefore important to supply electrical vehicles with recharging stations to increase their autonomy.

In this work, we investigate the problem of locating electronic replenishment stations for electric vehicles on the basis of traffic flows. Due to the limited driving range of electric vehicles, several stations may be required for a long trip, and the stations must be properly spaced on the path. This is essentially the Flow Refueling Location Problem (FRLP), first studied by [1]. They formulated the problem as a maximum-covering problem, which maximizes the total refueled flow based on pre-generated feasible station combinations for refueling the round trips. Another efficient maximum-covering formulation of the FRLP was proposed by [2], which does not require the pregeneration of all feasible station combinations. Instead, these authors introduced two binary variables on each node along every path indicating whether a station exists at that node and whether a driver at that node can reach another station further down the path without running out of fuel. Another type of model for the FRLP is based on the set covering problem in which the objective is to capture all the traffic flow with least station location cost. In [3], the authors define a variable for each node on a path indicating the remaining amount of fuel when vehicles reach that node. A trip can be refueled if the remaining amount of fuel at each node along the path is non-negative.

In this work, we present a simple, compact and more generalized maximum covering model as well as set covering model for the FRLP. In both models, we define a set of subpaths for each path in such a way that if each of these subpaths contains a replenishment station, the entire path flow is captured. Our model is also more general than the existing ones in the sense that it can solve the problem with any specified starting and ending fuel level and it can also deal with both one-way trips and round trips. Our two models were tested on real-life traffic data collected in Denmark.

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