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Project P7/36

Combinatorial Optimization: Metaheuristics and EXact methods (COMEX)

Coordinator: Bernard Fortz

Scientific Report 2014
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1 List of abbreviations

- **ACO-HCG**: Ant Colony Optimization / Heuristic Column Generation
- **AI**: Afriat's efficiency Index
- **DP**: Dynamic Programming
- **GARP**: Generalized Axiom of Revealed Preference
- **GRASP**: Greedy Randomized Adaptive Search Procedure
- **HARP**: Harmonic Axiom of Revealed Preference
- **HI**: Houtman and Maks Index
- **LOH**: Loss of Heterozygosity
- **LP**: Linear Program(ming)
- **MC-TOP-MTW**: Multi-Constraint Team Orienteering Problem with Multiple Time Windows
- **MEP**: Minimum Evolution Problem
- **MIP**: Mixed-Integer Program(ming)
- **MPI**: Money Pump Index
- **MRCPSP**: Multi-mode Resource-Constrained Project Scheduling Problem
- **MSTP**: Multiple Spanning Tree Protocol
- **PLOHP**: Parsimonious Loss of Heterozygosity Problem
- **PTP**: Prisoner Transportation Problem
- **SARP**: Strong Axiom of Revealed Preference
- **SBRP**: School Bus Routing Problem
- **SLS**: Stochastic Local Search
- **TP**: Transportation Problem
- **VI**: Varian Index
- **VRP**: Vehicle Routing Problem
- **WARP**: Weak Axiom of Revealed Preference

2 Composition of the network

- **P1 (ULB/GOM)**
  - Family Name : Fortz
  - First Name : Bernard
  - Title (Prof., Dr., . . .) : Professor
  - Institution : Université Libre de Bruxelles
  - Institution's abbreviation : ULB
  - Faculty/Department :Sciences/Computer Science
  - Research Unit : Graphs and Mathematical Optimization
  - Road/Street, n° : Boulevard du Triomphe, CP 212
  - Postal Code : 1050
  - Town/City : Brussels
  - Country : Belgium
  - Tel : +32 2 650 3095
  - Tel secretariat : +32 2 650 5609
  - Fax : +32 2 650 5609
  - E-mail : Bernard.Fortz@ulb.ac.be
  - Website : `http://homepages.ulb.ac.be`

- **P2 (ULg)**
  - Family Name : Crama
  - First Name : Yves
  - Title (Prof., Dr., . . .) : Professor
  - Institution : Université de Liège
  - Institution's abbreviation : ULg
  - Faculty/Department : HEC Management School
  - Research Unit : QuantOM – Center for Quantitative Methods and Operations Management
  - Road/Street, n° : Rue Louvrex 14 (N1)
  - Postal Code : 4000
  - Town/City : Liège
  - Country : Belgium
  - Tel : +32 4 366 3077
  - Tel secretariat : +32 4 232 7207
  - Fax : +32 4 232 7229
  - E-mail : Y.Crama@ulg.ac.be
  - Website : `http://www.quantom.hec.ulg.ac.be`
- **P3 (UHasselt)**
  - Family Name : Janssens
  - First Name : Gerrit
  - Title (Prof., Dr., . . .) : Prof.
  - Institution : Universiteit Hasselt
  - Institution's abbreviation : UHasselt
  - Faculty/Department :Business Economics
  - Research Unit : Logistics
  - Road/Street, n° : Agoralaan 1
  - Postal Code : B-3590
  - Town/City : Diepenbeek
  - Country : Belgium
  - Tel : +32-11-269119
  - Tel secretariat : +32-11-269105
  - Fax : +32-11-269199
  - E-mail : gerrit.janssens@uhasselt.be
  - Website : `http://www.uhasselt.be/gerrit.janssens`

- **P4 (UA)**
  - Family Name : Sörensen
  - First Name : Kenneth
  - Title (Prof., Dr., . . .) : Prof. Dr.
  - Institution : University of Antwerp
  - Institution's abbreviation : UA
  - Faculty/Department : Faculty of Applied Economics / Department of Environment, Technology and Technology Management
  - Research Unit : ANT/OR – University of Antwerp Operations Research Group
  - Road/Street, n° : Prinsstraat 13
  - Postal Code : 2000
  - Town/City : Antwerp
  - Country : Belgium
  - Tel : +32 3 265 40 48
  - Tel secretariat : +32 3 265 41 37
  - Fax : -
  - E-mail : kenneth.sorensen@ua.ac.be
  - Website : `http://antor.ua.ac.be`
- **P5 (KUL)**
  - Family Name : Spieksma
  - First Name : Frits
  - Title (Prof., Dr., . . .) : Prof.dr.
  - Institution : Katholieke Universiteit Leuven
  - Institution's abbreviation : KUL
  - Faculty/Department :Faculty of Business and Economics
  - Research Unit : ORSTAT
  - Road/Street, n° : Naamsestraat 69
  - Postal Code : 3000
  - Town/City : Leuven
  - Country : Belgium
  - Tel : +32 16 326976
  - Tel secretariat : +32 16 326745
  - Fax : + 32 16 326791
  - E-mail : frits.spieksma@econ.kuleuven.be
  - Website : `http://www.econ.kuleuven.be/eng/fetew/medewerker/userpage.aspx?PID=918`

- **P6 (ULB/IRIDIA)**
  - Family Name : Stützle
  - First Name : Thomas
  - Title (Prof., Dr., . . .) : Dr.
  - Institution : Université libre de Bruxelles
  - Institution's abbreviation : ULB
  - Faculty/Department :CoDE
  - Research Unit : IRIDIA
  - Road/Street, n° : Av. F. Roosevelt 50
  - Postal Code : 1050
  - Town/City : Brussels
  - Country : Belgium
  - Tel : +32 2 650 31 67
  - Tel secretariat : +32 2 650 27 29
  - Fax : +32 2 650 27 15
  - E-mail : stuetzle@ulb.ac.be
  - Website : `http://iridia.ulb.ac.be/~stuetzle`
- **P7 (UCL)**
  - Family Name : Van Vyve
  - First Name : Mathieu
  - Title (Prof., Dr., . . .) : Prof.
  - Institution : Université catholique de Louvain
  - Institution's abbreviation : UCL
  - Faculty/Department :Louvain School of Management (LSM)
  - Research Unit : Center for Operations Research and Econometrics (CORE/ IMMAQ)
  - Road/Street, n° : Voie du Roman Pays, 34
  - Postal Code : 1348
  - Town/City : Louvain-la-Neuve
  - Country : Belgium
  - Tel : +3210478161
  - Tel secretariat : +3210474321
  - Fax : +3210474301
  - E-mail : Mathieu.vanvyve@uclouvain.be
  - Website : `http://www.uclouvain.be/mathieu.vanvyve`

- **INT1 (UM)**
  - Family Name : Van Hoesel
  - First Name : Stan
  - Title (Prof., Dr., . . .) : Prof.
  - Institution : University Maastricht
  - Institution's abbreviation : UM
  - Faculty/Department :School of Business and Economics/Quantitative Economics
  - Research Unit : Operations Research
  - Road/Street, n° : Tongersestraat 53
  - Postal Code : 6211 LM
  - Town/City : Maastricht
  - Country : The Netherlands
  - Tel : +31 43 3883727
  - Tel secretariat : +31 43 3883834
  - Fax : +31 43 3884874
  - E-mail : s.vanhoesel@maastrichtuniverity.nl
  - Website : `http://www.maastrichtuniversity.nl`
- **INT2 (UdeM)**
  - Family Name : Gendron
  - First Name : Bernard
  - Title (Prof., Dr., . . .) : Prof.
  - Institution : Université de Montréal
  - Institution's abbreviation : UdeM
  - Faculty/Department :
  - Research Unit : CIRRELT (Interuniversity Research Centre on Enterprise Networks, Logistics and Transportation)
  - Road/Street, n° : CP 6128, SUCC Centre-ville
  - Postal Code : QC H3C 3J7
  - Town/City : Montréal
  - Country : Canada
  - Tel : 514.343.7240
  - Tel secretariat : 514.343.7575
  - Fax : 514.343.7121
  - E-mail : Bernard.Gendron@cirrelt.ca
  - Website : `http://www.cirrelt.ca`

3 Overview of scientific results and networking activities

The main objectives of the Combinatorial Optimization: Metaheuristics and EXact methods (COMEX) project are:

- Bring together the available Belgian expertise on combinatorial optimization problems, exploit synergies between the partner research groups, and create a network with a sufficient mass to attract young and experienced top-level scientists in Belgium, and further financing for research in the field.
- Train young researchers in the field of combinatorial optimization. These profiles are in high demand, both in academic research centers worldwide and in private organizations.
- Develop new models, algorithmic techniques and implementations for complex, large-scale combinatorial optimization problems.
- Develop new international collaborations with other large teams working in the field of combinatorial optimization.

The project is currently hiring 18 researchers, among the 7 partners. The annual meeting and the 20th Belgian Workshop on Mathematical Optimization were two opportunities for all partners to get together, present their research activities and discuss future collaborations. High quality tutorials during the workshop, in addition to the day-to-day follow-up of the students in each team ensured that the second objective is met. The visibility of the network was ensured through participations to national and international conferences, and in particular through dedicated sessions at the ORBEL conference.

Interactions between the partners were also initiated or pursued through several bilateral meetings between teams over the year.

The main research directions followed in the project are:

- Study and modelling of problems.
- Advancements in algorithmic techniques.
- Implementation of solution methods for large-scale, practically relevant problems.

The next section describes in detail achievements obtained in different application domains (Networks, Transportation & Logistics, Operations Management, Bio-informatics, Economics). Advancements in algorithmic techniques are reported in WP1.1 to WP1.4. For these workpackages, some possible collaborations between the teams have been identified and will be pursued in the future. Finally, the implementation of some solution methods is definitely a target for the end of the project, but some preliminary implementations for some specific problems are already available as reported further in this report.

The development of international collaborations was intensified. Bernard Gendron from CIRRELT (Montreal) was invited to the Belgian Workshop on Mathematical Optimization to give a tutorial talk. In the next year, a workshop in Montreal and the organisation of joint sessions at international conferences are planned. Joint meetings between KUL, ULB and the University of Maastricht also took place. These three partners presented the COMEX project during a meeting with the Supply Network Innovation Center of Procter & Gamble in Brussels in June 2014.

3.1 Networking activities

3.1.1 Meetings and workshops

- Annual meeting, ULB, November 19, 2013.
- 20th COMEX Belgian Workshop on Mathematical Optimization, La-Roche-en-Ardenne, April 24-25, 2014. In 2014, ULB took over the organization of the workshop which is now a COMEX activity. A meeting of the COMEX steering committee took place during the workshop.
- Various meetings between Leslie Perez (ULB/IRIDIA) and Alessia Violin (ULB/GOM) and occasionally in a larger group including Martine Labbé (ULB/GOM), Bernard Fortz (ULB/GOM), and Thomas Stützle (ULB/IRIDIA) to discuss common research on the automatic configuration of a Branch-and-Price algorithm for a pricing problem in road networks. The work is ongoing.
- Visit by Bernard Fortz and Martine Labbé (ULB) to the CODeS research group at the Technologiecampus Gent (KULeuven) in May 2014, discussing with Greet Vanden Berghe (KULeuven, Gent) on joint topics within the COMEX WP 2.3.
- Visit by An Caris and Kris Braekers (Universiteit Hasselt) to the Universiteit Maastricht in March 2014, discussing with Stan Van Hoesel and Tjark Vredeveld (operations research) and Janjaap Semijn en Lieven Quintens (supply chain management) on joint topics within the COMEX WP 2.2. A follow-up is planned in January 2015.
- Visit by An Caris, Kris Braekers and Gerrit Janssens (Universiteit Hasselt) to the CODeS research group at the Technologiecampus Gent (KULeuven) in November 2014, discussing with Greet Vanden Berghe (KULeuven, Gent) and Patrick De Causmaecker (KULeuven, Kortijk) on joint topics within the COMEX WP 2.2.

3.1.2 PhD Committees involving members of different COMEX teams

- Sabine Limbourg (ULg) is on the committee of Hanne Pollaris at UHasselt
- Yves Crama (ULg) is on the committee of Carlos Casorran at ULB/GOM
- Yves Crama (ULg) is on the committee of Bart Smeulders at KUL
- Yasemine Arda (ULg) is on the committee of Stef Moons at UHasselt
- Gerrit Janssens (UHasselt) was on the PhD committee and jury of Thierry Pironet (ULg) (thesis defended in September 2014)
- An Caris (UHasselt) is on the committee of Martine Mostert at ULg
- An Caris (UHasselt) was on the jury of Christine Van Overmeire at UA (thesis defended in January 2014)
- Greet Vanden Berghe (KUL) is on the committee of Yves Molenbruch at UHasselt
- Kenneth Sörensen (UAntwerp) is on the committee of Jeroen Corstjens at UHasselt

- Kenneth Sörensen (UAntwerp) is on the committee of Véronique François at ULg
- Thomas Stützle (ULB/IRIDIA) is co-supervisor of the thesis of Nguyen Thi Thanh Dang (KUL)
- Thomas Stützle (ULB/IRIDIA) is on the committee of Martim Moniz at ULB/GOM
- Thomas Stützle (ULB/IRIDIA) was on the jury of Alessia Violin at ULB/GOM (thesis defended in December 2014)

3.2 Dissemination

3.2.1 Website and mailing list

The website of the project is `http://comex.ulb.ac.be`. Two mailing lists are also used:

comex-project@euro-online.org: This is an internal mailing list used for the exchange of informations between researchers involved in the project. Archives of the mailing list are publicly available at
http://www.euro-online.org/pipermail/comex-project/.

comex-announces@euro-online.org: This public mailing list is used to announce events (seminar, workshops, ...) related to the dissemination of the project research activities. Archives of the mailing list are publicly available at
http://www.euro-online.org/pipermail/comex-announces/.

3.2.2 Publications

The list of publications emanating from the project is available in Section 6.

3.2.3 Conferences and Workshops

- **ORBEL 28, Mons, January 30-31, 2014**

  A stream of sessions was organized, spanning the whole duration of the conference. Recent work of researchers involved in the COMEX project were presented in 17 talks spanning 5 sessions.

- **20th COMEX Belgian Mathematical Programming Workshop**

  The COMEX network took over the organization of the workshop. The workshop consisted in 14 presentations by PhD students and postdoctoral researchers, and two tutorial talks:

  - Ruediger Schultz, Universität Duisburg-Essen
    "Stochastic Programming - Some Classical Basics and Recent Developments"
  - Bernard Gendron, CIRRELT
    "Decomposition Methods for Network Design"

- Plenary talks by COMEX members at international conferences:

- Frits Spieksma. *On constructing Round-Robin Schedules*. Plenary talk given at the Fourteenth Encuentro de Matemática y sus Aplicaciones, Quito, Ecuador, Sept. 2014.
- Frits Spieksma. *An overview of multi-index assignment problems*. Plenary talk given at the Workshop on Tractable special cases of hard combinatorial optimization problems, Graz, Austria, Dec. 2014.
- Thomas Stützle. *Automated Algorithm Configuration: Advances and Prospects*. Plenary talk given at the 8th International Symposium on Intelligent Distributed Computing (IDC'2014), Madrid, Spain, 2014.
- Thomas Stützle. *Automated Algorithm Configuration: Beyond Parameter Tuning*. Plenary talk given at the Workshop on Rough Sets: Theory & Applications at the Joint Rough Set Symposium, Granada, Spain, 2014.
- Thomas Stützle. *Automated Algorithm Configuration: Beyond Parameter Tuning*. Plenary talk given at the EVOLVE 2014 conference, Bejing, China, 2014.
- Thomas Stützle. *Towards Automated Algorithm Configuration*. Plenary talk given at the 2nd Brazilian Conference on Intelligent Systems (BRACIS-13), Fortaleza, Brazil, 2013.
- Thomas Stützle and Manuel López-Ibáñez. Tutorial on *Automatic (Offline) Configuration of Algorithms* at the Genetic and Evolutionary Computation Conference, GECCO 2014, Vancouver, Canada, Juli 2014 (with Manuel López-Ibáñez).
- Thomas Stützle. Tutorial on *Stochastic local search algorithms: an algorithm engineering perspective* at the 2nd Brazilian Conference on Intelligent Systems (BRACIS-13), Fortaleza, Brazil, October 2013.

3.2.4 Seminars

1. ULB/GOM

   - Thursday October 24, 2013
     Integer programming models for open stack problems
     Luigi De Giovanni (University of Padova, Italy)
   - Thursday October 31, 2013
     Exact algorithms for Weak Roman Domination
     Mathieu Chapelle (Algorithmique, ULB, Belgium)
   - Thursday November 7, 2013
     Large-Scale Reformulations of Combinatorial Problems: Not All Master Problems are Created Equal
     Antonio Frangioni (Università di Pisa, Italy)
   - Thursday November 14, 2013
     Some Math Programming and Game Theoretic approaches for the design of Robust Railway Networks Justo Puerto (University of Seville, Spain)

- Thursday November 21, 2013
  Global Liner Shipping Network Design
  Shahin Gelareh (University of Artois, France)
- Thursday March 13, 2014
  Refinement heuristics for capacitated extended-ring network design
  Alessandro Hill (Universiteit Antwerpen)
- Thursday March 27, 2014
  Nurse rostering models and algorithms
  Greet Vanden Berghe (KUL)
- Thursday June 5, 2014
  A model for the BitCoin block chain that takes propagation delays into account.
  Peter Taylor (U. Melbourne)
- Thursday June 5, 2014
  Approaches to bilevel programs with interval coefficients
  Carmen Galé (Universidad de Zaragoza)
- Thursday June 12, 2014
  Service start time optimization in elementary shortest path problems with resource constraints
  Yasemin Arda (Université de Liège)
- Monday September 8, 2014
  Gas network operation and optimization under uncertainty
  Jonas Schweiger (Zuse Institute Berlin, Germany)

2. ULg

- Tuesday March 25, 2014
  Supply Chain Planning: software support and promising fields of future research
  Prof. Dr. Herbert Meyr (Universität Hohenheim, Stuttgart)
- Thursday April 3, 2014
  Constraint programming: an overview
  Pierre SCHAUS (Université Catholique de Louvain)
- Tuesday May 6, 2014
  Automatic algorithm configuration methods and automatic design of metaheuristics
  Franco Mascia & Manuel López-Ibáñez (IRIDIA, ULB)
- Monday September 15, 2014
  Multiobjective combinatorial optimization: current and future challenges
  Thibaut Lust (Université Pierre et Marie Curie)
- Thursday October 16, 2014
  A bi-objective homecare scheduling problem: analyzing the trade-off between costs and patient convenience
  Kris Braekers (Hasselt University)
- Friday November 28, 2014
  Modeling convex subsets of points
  Prof. Maurice Queyranne (Université Catholique de Louvain)

3. KULeuven

- Tuesday November 5, 2013
  Decomposition of intervals in lattices: mathematical and computational challenges
  Patrick De Causmaecker (CODeS, KULeuven)
- Monday December 9, 2013
  A Combinatorial Benders' Decomposition for the Lock Scheduling Problem
  Jannes Verstichel (CODeS, KULeuven)
- Tuesday January 14, 2014
  Towards a spatio-temporal form of entropy
  Christophe Claramunt (French Naval Academy Research Institute)
- Monday February 2, 2014
  Cutting and packing problems
  Thiago Alves de Queiroz (Institute of Computing, State University of Campinas, Brazil)
- Tuesday March 25, 2014
  Bin packing problems with bins of different sizes: lower bounds and heuristic algorithms / The continuous Berth Allocation Problem in a container terminal with multiple quays
  Ramón Alvarez-Valdés (University of Valencia, Spain)
- Friday April 11, 2014
  Applications of automatic configuration/tuning, generating hybrid local search algorithms from a grammar
  Manuel López-Ibáñez (ULB/IRIDIA)
- Tuesday April 22, 2014
  Static Stability Algorithm for the Container Loading Problem
  António Galrão Ramos (INESC-TEC, Porto, Portugal)
- Monday May 5, 2014
  On the Generalized Directed Rural Postman Problem
  Thais Ávila (Universitat de València, Spain)
- Tuesday May 6, 2014
  Bilevel programming and price optimization problems Martine Labbé (ULB/GOM)
- Tuesday May 6, 2014
  Time-dependent combined network design and routing optimization
  Bernard Fortz (ULB/GOM)
- Monday May 12, 2014
  Cross-domain Heuristic Search Using a Tensor-based Hyper-heuristic
  Ender Ozcan (University of Nottingham, UK)
- Tuesday June 3, 2014
  Column generation for constrained-based clustering
  Behrouz Babaki (DTAI group, KU Leuven)
- Tuesday June 3, 2014
  Proportional Optimization and Fairness: Applications

Wieslaw Kubiak (Faculty of Business Administration, Memorial University of Newfoundland Newfoundland and Labrador, Canada)

- Tuesday June 3, 2014
  Challenges for pathplanning in highly dynamic environments
  Ignace Saenen (MMLab, UGent-iMinds)
- Friday June 6, 2014
  A Local Search Approach for Binary Programming : Feasibility Search
  Haroldo Santos (Universidade Federal de Ouro Preto, Brazil)
- Tuesday June 10, 2014
  Lagrangian Particle Swarm Optimisation for the Shift Minimisation Personnel Task Scheduling Problem
  Andreas Ernst (CSIRO, Australia)
- Wednesday June 11, 2014
  Network flow formulations for nurse rostering
  Pieter Smet (KUL - CODeS)
- Tuesday August 12, 2014
  On Sales Districting Problems
  Joerg Kalcsics (KIT Institute of Operations Research)
- Thursday, August 14, 2014
  Lagrangian Relaxations: where Nondifferentiable Optimization Meets Integer Programming
  Enrico Gorgone (ULB)
- Thursday, September 11, 2014
  Mathematical Models to scheduling problems in an automated storage and retrieval system
  Fulgencia Villa (Universidad Politecnica de Valencia)
- Thursday, September 11, 2014
  Shamrock: a Java 8 library supporting various types of routing applications
  Joris Maervoet (KUL - CODeS)
- Monday, September 29, 2014
  Constraint Programming Meets Data Mining
  Thomas Sys (KUL - CODeS)
- Monday, September 29, 2014
  Integrating CP, LP and Decision Diagrams for the Time-Dependent TSP
  Joris Kinable (KUL - CODeS)
- Friday October 10, 2014
  The Home Care Crew Scheduling Problem / The Patient Admission Scheduling problem
  Jesper Larsen(Technical University of Denmark - DTU)

4. ULB/IRIDIA

- Holger H. Hoos, *Machine Learning & Optimisation: Promise and Power of Data-driven, Automated Algorithm Design*, IRIDIA, ULB, April 10, 2014.

- Holger H. Hoos, *A Bootstrap Approach to Analysing the Scaling of Empirical Runtime Data with Problem Size*, IRIDIA, ULB, April 8, 2014.
- Gianpiero Francesca, *AutoMoDe: A Novel Approach to the Automatic Design of Control Software for Robot Swarms*, IRIDIA, ULB, January 14, 2014.

It is also worth mentioning that at ULB/IRIDIA, regular optimization group meetings and optimization reading group meetings are done (12 in the reporting period). In the optimization meetings IRIDIA postdoctoral and PhD students present their ongoing work for informal discussions while in the optimization reading groups, recent interesting articles are presented and actively discussed. Sometimes also new ideas for papers arise from these reading group meeting.

3.2.5 Others

In 2014 researchers in CODeS won the VEROLOG competition [1].

[1] http://verolog.deis.unibo.it/news-events/general-news/verolog-solver-challenge-2014-final-results

4 Research achievements

WP 0 Management / Dissemination / Training of young researchers

See Section 3.

WP 1.1 Exact methods

In [1], Abdel Aly and Mathieu Van Vyve (UCL) investigate how to solve several classical network flow problems using secure multi-party computation. They consider the shortest path problem, the Minimum Mean Cycle problem and the Minimum Cost Flow problem. To the best of our knowledge, this is the first time the two last problems have been addressed in a general multi-party computation setting. Furthermore, the study highlights the complexity gaps between traditional and secure implementations of the solutions, to later test its implementation. It also explores various trade-offs between performance and security. Additionally it provides protocols that can be used as building blocks to solve complex problems. Applications of this work can be found in: communication networks, routing data from rival company hubs; benchmarking, comparing several IT appliances configurations of rival companies; distribution problems, retailer/supplier selection in multi-level supply chains that want to share routes without disclosing sensible information; amongst others. The work was presented at ICISC 2014 in Seoul and will soon be published in the proceedings of this highly ranked conference.

In [46] Mathieu Van Vyve (UCL) and Claudio Telha (UCL) consider a continuous-time variant of the classical Economic Lot-Sizing (ELS) problem. In this model, the setup cost is a continuous function with lower bound Kmin > 0, the demand and holding costs are integrable functions of time and the replenishment decisions are not restricted to be multiples of a base period. Starting from the assumption that certain operations involving the setup and holding cost functions can be carried out efficiently, we argue that this variant admits a simple approximation scheme based on dynamic programming: if the optimal cost of an instance is OPT, we can find a solution with cost at most $(1+\epsilon)OPT$ using no more than a number of oracle calls polynomial in $1/\epsilon$, $\log(OPT)$ and a natural input-size measure that is invariant under simple scaling of the costs and the demand. Besides dynamic programming, this approximation scheme builds on a novel algorithmic approach for Economic Lot Sizing problems.

Dash, Gunluk and Wolsey (UCL) [8] study the convex hull of the continuous knapsack set which consists of a single inequality constraint with n non-negative integer and m non-negative bounded continuous variables. When $n = 1$, this set is a slight generalization of the single arc flow set studied by Magnanti, Mirchandani, and Vachani (1993). They first show that in any facet-defining inequality, the number of distinct non-zero coefficients of the continuous variables is bounded by $2n - n$. The next result is to show that when $n = 2$, this upper bound is actually 1. This implies that when $n = 2$, the coefficients of the continuous variables in any facetdefining inequality are either 0 or 1 after scaling, and that all the facets can be obtained from facets of continuous knapsack sets with $m = 1$. The convex hull of the sets with $n = 2$ and $m = 1$ is then shown to be given by facets of either two-variable pure-integer knapsack sets or continuous knapsack sets with $n = 2$ and $m = 1$ in which the continuous variable is unbounded, for which the convex hull is known. Finally they show (via an example) that when $n = 3$, the non-zero coefficients of the continuous variables can take different values.

In [27] Nesterov (UCL) and Shikman develop new subgradient methods for solving nons-

mooth convex optimization problems. These methods are the first ones, for which the whole sequence of test points is endowed with the worst-case performance guarantees. The new methods are derived from a relaxed estimating sequences condition, which allows reconstruction of the approximate primaldual optimal solutions. This type of methods is applicable for solving the Lagrangean relaxation some structured large-scale MIPs. Preliminary numerical experiments confirm a high efficiency of the new methods.

Van Vyve et al. (UCL) [48] consider several variants of the two-level lot-sizing problem with one item at the upper level facing dependent demand, and multiple items or clients at the lower level, facing independent demands. They first show that under a natural cost assumption, it is sufficient to optimize over a stock-dominant relaxation. They further study the polyhedral structure of a strong relaxation of this problem involving only initial inventory variables and setup variables. Several variants are considered: uncapacitated at both levels with or without start-up costs, uncapacitated at the upper level and constant capacity at the lower level, constant capacity at both levels. They finally demonstrate how the strong formulations described improve our ability to solve instances with up to several dozens of periods and a few hundred products.

WP 1.2 Metaheuristics

WP 1.2.1 Aims and scope

Three main goals have been set for this work package:

- Give expertise and possibly hands-on help to partner groups who at some stage of their research need to implement metaheuristic algorithms but do not have the particular expertise
- Discover the relationship between the performance of metaheuristic components and different problems
- Obtain scientific insight into the working of (components of) metaheuristic frameworks

Concerning the first objective, the different COMEX teams are now closely collaborating and that metaheuristics are developed in groups that previously focused more on exact methods (and vice versa).

WP 1.2.2 Metaheuristics development

Several metaheuristics are developed within the COMEX project framework. The flexibility of metaheuristics is demonstrated by the size and the complexity of problems that can be solved using these techniques.

Although different types of metaheuristics are being developed by the various research teams, there seems to be a convergence on component-based techniques of the local search type. This is in alignment with the current views expressed in the metaheuristics literature. “Pure” metaheuristics of the evolutionary or metaphor-based type have not been developed by any of the research groups. Indeed, there is a growing resentment in the field against the indiscriminate use and development of ever more “novel methods” based on some kind of metaphor.

Several teams are analyzing combinations of (meta)heuristics with exact methods, using both types of algorithms for subproblems where they seem most suitable. The component-based view on metaheuristics seems to have pervaded throughout the COMEX community. Also, there is considerable research on the development of "hyper"-heuristics.

There is considerable research on tuning of metaheuristic algorithms, either automatic (by, e.g., the irace software) or manually, through a controlled statistical experiment. In this way, the development of metaheuristics is slowly losing its status as an "art". "Metaheuristic engineering" could be coined as a new way to describe the more systematic development of heuristic optimization algorithms the community is currently trying to achieve.

As a conclusion, it can be said that the metaheuristics developed within the COMEX project are at the forefront of the field, both in terms of their quality as their scientific underpinning.

Further research will certainly focus on the development of other powerful heuristic methods for different optimization problems, and on the study of metaheuristics in general, to find out why and how these methods work as well as they do.

Research is ongoing into the development of metaheuristics in general, i.e., into the field of metaheuristics as a whole. A presentation by K. Sörensen (UAntwerpen) at the latest ORBEL conference on "A history of metaheuristics" discussed the paradigm shifts this very recent research field has gone through. This will result in a book chapter to be published in 2015. An article by K. Sörensen in ITOR ("Metaheuristics, the metaphor exposed") that was written before the start of the COMEX project but published early this year, has seen considerable interest. Some journals (like the flagship "Journal of Heuristics" have changed their editorial policy to no longer accept pure "metaphor-based" metaheuristics any more. Certainly partly as a result of this article. K. Sörensen also gave a presentation at the latest COMEX meeting on metaheuristics and metaphors entitled "Metaphors considered harmful."

WP 1.3 Integration of exact methods and heuristics

This work package deals with research that is targeted to integrate techniques from methods in integer and, more general, mathematical programming and (meta)heuristics into hopefully better performing, hybrid algorithms. This is a challenging but also very promising direction in combinatorial optimization. It is challenging also because integer programming (IP) and the heuristic optimization communities have been working in isolation from each other. As the COMEX project combines research groups rooted in either of these domains, it is also an opportunity to explore such techniques. Despite the early stage in the project, some work in this direction has been done and initiated.

The number of possible ways of combining exact and heuristic methods is multiple and often problem specific. In the following, we discuss several works that have been developed or where currently progress is being made. These works concern the derivation of heuristics methods from exact formulations, the solution of stochastic optimization problems, the usage of variable fixing strategies to derive simpler sub-problems for exact solution, and simply the experimental comparison of exact and heuristic methods to identify their relative strengths.

B. Fortz (ULB/GOM), C. Requejo and O. Oliveira (University of Aveiro, Portugal) have studied the problem of reconstructing a tree network by knowing only its set of terminal nodes and their pairwise distances, so that the reconstructed network has its total edge weight minimized. This problem has applications in several areas, namely the inference of phylogenetic trees and the inference of routing networks topology. In their research they used nowadays

maybe standard techniques that use the idea of local search inside integer programes, namely the development of efficient local branching heuristics for solving the problem as well as the study of the feasibility pump.

T. Dokka (KUL), Y. Crama (ULg) and F.C.R. Spieksma (KUL) study a special class of axial multi-dimensional assignment problems called multi-dimensional vector assignment (MVA) problems. They analyze the worst case approximation ratio of a class of polynomial-time heuristics for MVA, namely, sequential heuristics based on iterative (exact) solutions of bipartite assignment problems. They provide tight approximation ratios under various assumptions (monotonicity, submodularity, additivity) on the cost function. This work was already announced in a previous report. It was completed in 2014 and published in [9]. It was presented at the Graphs and Optimization conference in Sirmione, Italy.

Y. Arda (ULg), Y. Crama (ULg), D. Kronus (ULg), Th. Pironet (ULg) and P. Van Hentenryck have investigated a multi-period vehicle loading problem with stochastic information regarding the release dates of items to be transported. This work was already announced in a previous report. It was completed in 2014 and published as [3].

C. Paquay, M. Schyns and S. Limbourg (ULg) have developed a mixed integer programming formulation for the three dimensional bin packing problem deriving from an air cargo application (that is, optimising the loading of boxes into containers). This work was already announced in a previous report. It was completed in 2014 and published as [33].

In their current work, Paquay, Limbourg, Oliveira and Schyns are developping a set of MIP-based constructive matheuristics based on the formulation used in [33] for the three dimensional bin packing problem with transportation constraints. A first try is to adapt a Relax-and-Fix (RF) heuristic to our MIP. The RF methodology is an iterative procedure which decomposes a large-scale MIP problem into several easier subproblems in order to get an initial feasible solution for the original problem. The integrality restriction of some variables is relaxed in subproblems, reducing the computational times. Two other MIP-based constructive heuristics, inspired from the RF heuristic, have also been adapted to this context. The Insert-and-Fix (IF) heuristic relies on the idea to insert boxes step by step inside containers. The Fractional Relax-and-Fix (FRF) heuristic is based on the merge between the two previous methods: at each iteration of this algorithm, a set of boxes is inserted (as in IF) while a subset of their variables has the integrality restriction relaxed (as in RF). These three MIP-based constructive heuristics are compared to a greedy best-fit decreasing algorithm designed especially for this purpose. Prelminiary versions of this work have been presented at the 20th IFORS Conference, Barcelona, Spain (http://hdl.handle.net/2268/171198), at the 11th ESICUP Meeting (http://hdl.handle.net/2268/165167) and at the 28th annual conference of the Belgian Operational Research Society. (http://hdl.handle.net/2268/166703).

Jannes Verstichel, Patrick De Causmaecker, Frits Spieksma, and Greet Vanden Berghe developed exact and heuristic approaches to the problem of placing ships in locks, which is an important problem in the area of lock scheduling. This work was already announced in a previous report. It was completed in 2014 and published in two papers [54, 55].

A direct solution of the problem using an IP formulation and commercial IP solvers turned out to be computationally heavy. Hence, a decomposition approach was developed, where a heuristic method is used to improve the lower bound on the number of ships that can be placed in a same chamber, resulting in significant computational improvements. A comparison of the developed exact and heuristic algorithms shows that the decomposition-based approaches are rather effective; however, if high quality solutions are required in very short computation times

(e.g. less than a second), the heuristic algorithms are clearly the method of choice. Interestingly, the heuristic algorithms also find very high quality solutions (on average only 3.24% above optimal on the largest instances considered) within this short time. The possibility of having predictable run-times and high solution quality was deemed to be important in the context of the considered problem, as in the lock scheduling problem, frequently a fast solution to the problem of where to place ships is required.

The travelling salesman problem (TSP) is one of the most prominent NP-hard combinatorial optimisation problems. After over fifty years of intense study, the TSP continues to be of broad theoretical and practical interest. Using a novel approach to empirical scaling analysis, which in principle is applicable to solvers for many other problems, Hoos (UBC, Canada) and Stützle (ULB/IRIDIA) demonstrate that some of the most widely studied types of TSP instances tend to be much easier than expected from previous theoretical and empirical results [14]. In particular, they show that the empirical median run-time required for finding optimal solutions to random uni-form Euclidean (RUE) instances – one of the most widely studied classes of TSP instances – scales substantially better than $\Omega(2^n)$ with the number n of cities to be visited. The Concorde solver, for which they achieved this result, is the best-performing exact TSP solver, and has been applied to a broad range of real-world problems. Furthermore, they show that even when applied to a broad range of instances from the prominent TSPLIB benchmark collection for the TSP, Concorde exhibits run-times that are surprisingly consistent with our empirical model of Concorde's scaling behaviour on RUE instances. This result suggests that the behaviour observed for the simple random structure underlying RUE is very similar to that obtained on the structured instances arising in various applications.

WP 1.4 Testing and configuration of parameters

This work-package deals with all the research efforts that are dedicated to specific usages and developments in the direction of automatic algorithm configuration and tuning. In many of the contributions that are described in this report experimental analysis and experimental design play a significant role in the developments done. Many of these applications of experimental analysis and design follow mainly common standards that are being more widely spread in algorithmically oriented research. Specific guidelines and the development of a comparison standard for heuristics and exact algorithms will be undertaken later in the project. In the report on work-package 1.4, we focus on the usage of and the development of advanced techniques for supporting the offline and online configuration of algorithms and algorithm selection approaches. Such methods are currently a hot topic in research on heuristic and also exact methods. In the following, we first report on applications of offline configuration methods where these have or probably will be crucial to obtain very high performance algorithms. We then discuss the research targeted towards the development and improvement of automatic configuration methods.

WP 1.4.1 Applications of tuning and configuration methods

In a collaboration between the IRIDIA and the GOM team of Université libre de Bruxelles, Bernard Fortz, Martine Labbé, Alessia Violin, Leslie Perez, and Thomas Stützle are examining the impact automatic algorithm configuration has on the performance and the engineering of branch-and-price algorithms for a network pricing problem. In this work is considered the

automatic configuration of the branch-and-price part but also in addition the parameters of the underlying solver, which in this case is SCIP, version 3.0.1. The results that have obtained with the tuning are currently included into the manuscript of the PhD thesis of Alessia Violoin, which will be defended in November / December 2014 and collaboration will continue after the defense.

Many studies in the literature have applied multi-objective evolutionary algorithms (MOEAs) to multi-objective combinatorial optimization problems. Few of them analyze the actual contribution of the basic algorithmic components of MOEAs. These components include the underlying EA structure, the fitness and diversity operators, and their policy for maintaining the population. A team by Leonardo Bezerra, Manuel López-Ibáñez, and Thomas Stützle has compared seven MOEAs from the literature on three bi-objective and one tri-objective variants of the permutation flowshop problem [5]. The overall best and worst performing MOEAs are then used for an iterative analysis, where each of the main components of these algorithms is analyzed to determine their contribution to the algorithms' performance. Results confirm some previous knowledge on MOEAs, but also provide new insights. Concretely, some components only work well when simultaneously used. Furthermore, a new best-performing algorithm was discovered for one of the problem variants by replacing the diversity component of the best performing algorithm (NSGA-II) with the diversity component from PAES. In a next step, they have exploited the insights that we have obtained in the previous study to design a component-wise framework for MOEAs that allows to combine algorithmic components from different MOEAs. The number of available algorithmic components is large, though, and an algorithm designer working on a specific application cannot analyze all possible combinations. They have therefore considered the automatic design of MOEAs, extending previous work on other multi-objective metaheuristics. Experiments on four variants of the permutation flowshop problem that differ on the number and nature of the objectives have been considered. Their results show that the automatically designed MOEAs are able to outperform six traditional MOEAs, confirming the importance and efficiency of this design methodology [4].

Optimisation algorithms with good anytime behaviour try to return as high-quality solutions as possible independently of the computation time allowed. Designing algorithms with good anytime behaviour is a difficult task, because performance is often evaluated subjectively, by plotting the trade-off curve between computation time and solution quality. Yet, the trade-off curve may be modelled also as a set of mutually nondominated, bi-objective points. Using this model, López-Ibáñez and Stützle have proposed to combine an automatic configuration tool and the hypervolume measure, which assigns a single quality measure to a nondominated set. This allows to improve the anytime behaviour of optimisation algorithms by means of automatically finding algorithmic configurations that produce the best nondominated sets. Moreover, the recently proposed weighted hypervolume measure is used here to incorporate the decision-maker's preferences into the automatic tuning procedure. We report on the improvements reached when applying the proposed method to two relevant scenarios: (*i*) the design of parameter variation strategies for MAX-MIN Ant System, and (*ii*) the tuning of the anytime behaviour of SCIP, an open-source mixed integer programming solver with more than 200 parameters. The results of this research have been published in 2014 in the journal European Journal of Operational Research [22].

Ant Colony Optimization (ACO) was originally developed as an algorithmic technique for tackling NP-hard combinatorial optimization problems. Most of the research on ACO has focused on algorithmic variants that obtain high-quality solutions when computation time allows

the evaluation of a very large number of candidate solutions, often in the order of millions. However, in situations where the evaluation of solutions is very costly in computational terms, only a relatively small number of solutions can be evaluated within a reasonable time. Perez, López-Ibáñez and Stützle have investigated how different ACO algorithms behave if they have available only a very limited number of solution evaluations, say, 1000. They show that, after tuning the parameter settings for this type of scenario the best parameter settings are very different from the standard recommendations available in the literature [34].

WP 1.4.2 Development of tuning and configuration methods

Work on the analysis and improvement of automatic algorithm configuration techniques has followed several lines of research.

Automatic algorithm configuration methods are themselves heuristic algorithms that tackle a stochastic, non-linear mixed-variable black-box optimization problem. Leslie Perez, Manuel López-Ibáñez and Thomas Stützle have analyzed the impact specific parameters have on the performance of the irace method, which implements a flexible tool for the automatic configuration of algorithms. In fact, the irace software has itself specific parameters that enable the customization of the search process according to the tuning scenario. They have analyzed five parameters of irace: the number of iterations, the number of instances seen before the first elimination test, the maximum number of elite configurations, the statistical test and the confidence level of the statistical test. These parameters define some key aspects of the way irace searches and identifies good configurations. Originally, their values have been set based on rules of thumb and an intuitive understanding of the configuration process. This work aims at giving insights about the sensitivity of irace to these parameters in order to provide guidance for their settings and possible further improvements of irace. The article on this analysis has been published and been presented at the conference EvoCOP in April 2014 [6].

Based on further insights generated during the previously described study, a new version of the irace software package is currently being developed. One feature that has been added is a new handling of the elite configurations. Additional new features include the re-use of previously generated results to avoid re-computations. Although so far no new publications have been describing the new, so-called elite irace, it will be included in future software releases of the irace software.

Several grammar-based genetic programming algorithms have been proposed in the literature to automatically generate heuristics for hard optimization problems. These approaches specify the algorithmic building blocks and the way in which they can be combined in a grammar; the best heuristic for the problem being tackled is found by an evolutionary algorithm that searches in the algorithm design space defined by the grammar. Franco Mascia, Manuel López-Ibáñez, Jérémie Dubois-Lacoste and Thomas Stützle propose a novel representation of the grammar by a sequence of categorical, integer, and real-valued parameters [25]. They then use a tool for automatic algorithm configuration to search for the best algorithm for the problem at hand. Their experimental evaluation on the one-dimensional bin packing problem and the permutation flowshop problem with weighted tardiness objective shows that the proposed approach produces better algorithms than grammatical evolution, a well-established variant of grammar-based genetic programming. The reasons behind such improvement lie both in the representation proposed and in the method used to search the algorithm design space.

This parameterization of grammar rules is also relevant for recent work by the IRIDIA/ULB

team on the automatic generation of hybrid stochastic local search (SLS) algorithms. In their work, a unified structure that encompasses several such SLS methods (aka metaheuristics) has been proposed. From this structure, known SLS methods such as Iterated Greedy, Iterated Local Search, Simulated Annealing, Tabu Search, GRASP, and few others can be instantiated. At the same time, combinations of these SLS methods can be generated, thus, resulting in hybrid SLS algorithms. This work, started in 2013, has been continued in the new reporting period and the system been considerably improved and results for new problems been generated. At the moment, a summary of the developments is being written up and should be submitted soon for journal publication. Preliminary results have already been described in various occasions.

Initial research by Nguyen Dang and Patrick De Causmaecker considers automatic configuration as a multi-objective problem, where algorithm configurations need to be identified that provide a balance between different measures how the performance of algorithms can be evaluated. One such example they consider is the number of instances solved and the average computation time to optimum. They have considered several ways of how to tackle this problem and computational work is on the way.

IRIDIA researchers have contributed to the establishment of ACLIB, a benchmark library for algorithm configuration that is accessible at `http://www.aclib.net`. In fact, as the field of algorithm configuration matures and the number of available configuration procedures grows, so does a need for standardized problem definitions, interfaces, and benchmarks. Such a benchmark library would encourage reproducible research, facilitate the empirical evaluation of new and existing configuration procedures, reduce obstacles faced by researchers new to the community, and allow an objective scientific evaluation of strengths and weaknesses of different methods.

WP 2.1 Networks

2.1.1. Telecom

B. Fortz (GOM, ULB), L. Gouveia (CIO, Portugal) and M. Moniz (GOM, ULB) [10] continued to study the problem of optimally designing switched Ethernet networks by implementing the Multiple Spanning Tree Protocol. A new MILP model was developed (called RDMFF), that aggregates the strategies for designing spanning trees of models RDF (previously AF) and MFF. The linear programming relaxation of this model was shown to be stronger than the ones of the previous models. Furthermore, numerical experiments revealed that RDMFF competes well with RDF, in terms of effectiveness in solving instances to optimality.

A binary search method was also proposed, that solves successive MILPs, based on the aforementioned models, in an attempt to converge to a near-optimal solution. In each of these adapted MILPs, the objective is to find a single feasible solution that verifies the link utilization limit, given as an input by the binary search method, whilst trying to optimize a Min-Average type of objective. Numerical experiments revealed that this method was quite effective in finding near-optimal solutions, in cases where CPLEX, using any of the aforementioned models had not been able to.

B. Fortz (ULB/GOM) and D. Papadimitriou [11, 31, 32] studied a new combined optimization model for telecommunications networks that integrates network design decisions and routing decisions, with time-dependent demands. They compared a basic, aggregated model to a disaggregated, extended formulation that provides much tighter lower bounds at the cost of

a very high solving time. Together with E. Gorgone (ULB/GOM), they are also developing a Lagrangean decomposition approach to solve the problem. The Lagrangian Dual is solved by means of a non-smooth algorithm, the bundle method. The bundle code was enhanced with a specialized quadratic solver to handle the master problem.

E. Gorgone (ULB/GOM) and B. Gendron (CIRRELT) also studied the tuning and the testing of a (generalized) subgradient method combined with different rules for the stepsize and the search direction, for the standard network design problem. The algorithm includes the Primal-Dual variant designed by Yu. Nesterov and the incremental versions designed by D. Bertsekas.

2.1.2. Transportation

The transportation problem is a fundamental problem in Operations Research. In Vancroonenburg et al. [50], the RedBlue Transportation Problem (RBTP) is considered. RBTP is a generalization of the transportation problem where supply nodes are partitioned into two sets and so-called exclusionary constraints are imposed. RBTP was encountered in a hospital context, where patients need to be assigned to rooms. The problem's complexity is established, and two integer programming formulations are compared. Furthermore, a maximization variant of RBTP is presented, for which a constant-factor approximation algorithm is proposed. A computational study on the performance of the integer programming formulations and the approximation algorithms, concludes the paper.

The RBTP is a special case of a problem known as the Transportation Problem with Exclusionary Constraints (TPESC). Indeed, in the TPESC, arbitrary sets of supply nodes are given (for each demand node), only one of which is allowed to send flow to that particular demand node. A. Ficker and F. Spieksma studied to what extent positive results for RBTP can be generalized to TPESC.

A. De Corte and K. Sörensen have tackled the water distribution network design optimisation problem with an iterated local search technique. This problem aims at finding the optimal pipe configuration out of a discrete set of available pipe types, taking into account hydraulic principles, energy laws and customer requirements. A lot of research has been conducted on this mixed-integer, non-linear optimisation problem in the past, but the authors were the first to test the algorithm on a broad, real-life set of test instances, generated by HydroGen. A full-factorial experiment was conducted to find the best algorithm configuration and parameter settings. It was completed in 2014. It is currently under review in a special issue of *Networks: Metaheuristics in Network Optimization* and was presented at the *ORBEL28 Annual Meeting* (February 2014, Mons). Extensions of this problem are currently considered.

A. De Corte and K. Sörensen developed a tool, HydroGen, to create virtual test instances for water distribution network optimisation problems. HydroGen is able to generate a wide variety of benchmark networks of arbitrary size and varying characteristics.This library of test networks is available online at: http://antor.ua.ac.be/HydroGen. This work was completed in 2014. It was and published as: HydroGen: an Artificial Water Distribution Network Generator in *Water Resources Management* and presented at the *Wessex Urban Water Conference* (May 2014, Portugal).

2.1.3. Miscellaneous

J. Janssens (UA), L. Talarico (UA) and K. Sörensen (UA) study a decision model aimed at increasing security in a utility network (e.g. smart grid, water network). The model proposed, assumes that all edges and nodes have a certain probability of failing, due to malicious attacks, which can be reduced by applying appropriate security strategies. The goal is to reduce the risk for a disconnection in the network by applying these security strategies, taking into account a budget constraint. As this problem is combinatorial in nature, an efficient metaheuristic to solve it is proposed. This work has been registered as a working paper [16] and presented at The International Workshop on Simulation for Energy, Sustainable Development & Environment (SESDE2014), Bordeaux, France.

J. Janssens (UA), L. Talarico (UA) and K. Sörensen (UA) extended a model that they previously developed to increase security in a utility network. Attacks on nodes and all possible connections between any pair users are included in the newer model. The work has been registered in 2014 as a working paper at the University of Antwerp [17]. The results of this work have been presented at VIII ALIO/EURO Workshop on Applied Combinatorial Optimization in Montevideo, Uruguay.

B. Fortz (ULB/GOM), C. Requejo and O. Oliveira (University of Aveiro, Portugal) study the problem of reconstructing a tree network by knowing only its set of terminal nodes and their pairwise distances, so that the reconstructed network has its total edge weight minimized. This problem has applications in several areas, namely the inference of phylogenetic trees and the inference of routing networks topology. Phylogenetic trees allow the understanding of the evolutionary history of species and can assist in the development of vaccines and the study of biodiversity. The knowledge of the routing network topology is the basis for network tomography algorithms and it is a key strategy to the development of more sophisticated and ambitious traffic control protocols and dynamic routing algorithms. In 2014, the focus has been on the development of efficient feasibility pump and local branching heuristics for solving the problem.

D. Palhazi Cuervo (UA), K. Sörensen (UA) and P. Goos (KULeuven) developed a framework to generate experimental scenarios in which a complete randomization is not possible. For these cases, it is possible to generate experimental designs that explicitly take into account the experimental constraints and allow to perform a better analysis. This is done by by grouping the observations that are made under similar experimental conditions and by modelling the variation of the response due to the differences between the groups. These types of experiments are known as *multi-stratum experiments*. We have developed an algorithmic framework to generate optimal multi-stratum experiments in which the number of groups and the size of the groups are limited only by upper bounds. The algorithmic framework is based on a multi-level local search approach. The low level implements a extension of the coordinate-exchange algorithm and is in charge of optimizing the factor-levels configuration. The high level implements a variable neighborhood search (VNS) algorithm and is in charge of optimizing the grouping configuration. Limiting the experimental scenario only by upper bounds has proven to significantly improve the quality of the experimental designs generated. Additionally, the algorithm can consider more complex correlation structures than those traditionally used by multi-stratum experiments. We assume that that the observations in each group follow an autoregressive process of order one. In other words, observations that are performed closer to each other are more strongly correlated than observations that are performed further apart in

time or space. The algorithmic framework is described in the working paper by [29] and some preliminary results have been presented in [30].

WP 2.2 Transportation & Logistics

WP 2.2.1 Shortest Path Problems

Yasmine Arda (ULg), Yves Crama (ULg), and Hande Kücükaydin (ULg) [2] investigate an elementary shortest path problem with resource constraints where a single capacitated vehicle, initially located at a depot, must serve a set of customers while respecting their individual time windows. When the vehicle visits a customer, it delivers the customer's demand and collects a revenue in return for the delivery. The vehicle can start its trip at any desired time. The transportation cost is a function of both the total distance traveled and the duration of the assigned trip. The objective is to determine the service start time from the depot, the subset of customers to be served, and the trip to be performed so as to minimize the total loss, which is calculated as the difference between the transportation cost and the revenue collected from the customers. Two exact dynamic programming algorithms are developed to deal with an infinite number of Pareto-optimal states arising from the fact that the starting time and the duration of the trip act like continuous decision variables. Computational results obtained with these algorithms and with a faster heuristic for the elementary shortest path problem are reported. The paper also examines the performance of these algorithms when they are used to solve the pricing sub-problem arising in the framework of a column generation algorithm for a related vehicle routing problem with time windows.

WP 2.2.2 Intermodality

An Caris (UHasselt), Sabine Limbourg (ULg), Cathy Macharis (VUB), Tom Van Lier (VUB) and Mario Cools (ULg) [7] have identified research opportunities which will enable the further integration of inland waterway transport in the intermodal supply chain.

Bruno Santos, Sabine Limbourg (ULg) and Joana Carreira [38], discuss the impact of three freight transport policies aiming to promote railroad intermodal transport in Europe, and examine the case of Belgium as a testing ground. These policies consist in subsidizing intermodal transport operations (such as in Belgium, to stimulate rail transport), internalizing external costs (as recommended by the European Union in order to foster cleaner modes), and adopting a system perspective when optimizing the location of inland intermodal terminals. The study proposes an innovative mixed integer intermodal freight location-allocation model based on hub-location theory and deals with non-linear transport costs in order to replicate economies of distance. The analysis suggests that subsidizing has a significant impact on the volumes transported by intermodal transport, and, to a lesser extent, that optimizing terminal location increases the competitiveness of intermodal transport. The assumption, however, is that internalizing external costs can negatively impact the promotion of intermodality. This finding indicates that innovative last-mile transports are needed in order to reduce the external impacts of drayage operations.

In their research currently under way, Martine Mostert (ULg), An Caris (UHasselt) and Sabine Limbourg (ULg) investigate a three-mode bi-objective location model under economies of scale for intermodal transport. This research presents an innovative location-allocation model which focuses on both operational costs and CO2 emissions of transport. Costs and

emissions minimization mainly refers to energy optimization. However some diverging factors between both functions are expected. Indeed repair and maintenance costs may be lower for road than for rail, whereas emissions are expected to be higher for road than for rail. Decisions may change when both aspects are considered. This is why the possible opposition between costs and emissions is taken into account by including both functions in a multi-objective optimization model. The model represents the perspective of transportation companies, which have to support operational costs and try to minimize their total CO2 emissions. Their first objective, cost minimization, is quite straightforward from the economic perspective. The second objective, emission minimization, can be explained by marketing reasons or willingness to match CO2 emissions policies instigated by public authorities. The particularity of the model is to take into account economies of scale of intermodal transport by using non-linear cost and emission functions, instead of classically considering a discount factor on the long-haul travel. Another contribution is to analyze the network design by integrating three different modes of transport, i.e., road, intermodal using rail and intermodal using inland waterways transport. This research has been presented at the 20th IFORS Conference in Barcelona (http://hdl.handle.net/2268/174777).

Jannes Verstichel, Patrick De Causmaecker, Frits Spieksma and Greet Vanden Berghe (all KUL) consider a harbour with ships entering and leaving using locks. The ship placement problem constitutes a daily challenge for planners in tide river harbours. In essence, it entails positioning a set of ships into as few lock chambers as possible while satisfying a number of general and specific placement constraints. These constraints make the ship placement problem different from traditional 2D bin packing. A mathematical formulation for the problem is published in [54]. In addition, a decomposition model is developed which allows for computing optimal solutions in a reasonable time. Experiments on simulated and real-life instances show that the multi-order best- fit heuristic beats the other heuristics by a landslide, while maintaining comparable calculation times. Finally, the new heuristics optimality gap is small, while it clearly outperforms the exact approach with respect to calculation time. From a more general point of view, it is not only ship placement that matters. An integrated approach to solving the generalized lock scheduling problem is introduced. Three interrelated sub problems can be discerned: ship placement, chamber assignment and lockage operation scheduling. In their turn, these are closely related to the 2D bin packing problem, the assignment problem and the (parallel) machine scheduling problem respectively. A mixed integer linear programming model is presented in [55] and applied to instances from both inland locks and locks in a tide independent port. The experiments show that small instances incorporating a wide range of real-life constraints can be solved to optimality. The research by the same authors has been published in 2014 in Transportation Research (part E).

LucaTalarico (UA), Kenneth Sörensen (UA), Johan Springael (UA) and Genserik Reniers (UA) developed a multi-modal security-transportation model to allocate security resources within a chemical supply chain. The decision model is based on game theory and it can be employed to organize intelligence capabilities aimed at preventing terrorist attacks, avoiding (possibly huge) human and economic losses.

WP 2.2.3 Routing Problems

Reducing environmental impact, related regulations and potential for operational benefits are the main reasons why different partners of a closed loop supply chain share their Return-

able Transport Items (RTIs). Galina Iassinovskaia, Sabine Limbourg (ULg) and Fouad Riane are currently working on inventory-routing problems with pickups and deliveries of RTIs. A mixed-integer linear program is developed and tested on small instances. To handle realistic large size problems, a clustering algorithm is coupled with a simulation model. This hybrid heuristic allows assessing the benefits of information and RTIs sharing among partners. This work has been presented at the 20th IFORS Conference, Barcelona, Spain. See http://hdl.handle.net/2268/171331.

Maud Bay and Sabine Limbourg (ULg) are investigating a TSP model for electric vehicle deliveries, considering speed, loading and road grades The objective usually considered in sustainable transportation is to minimize pollution due to emissions, and equivalently energy consumption. Turning to electric mobility, driving range is the major concern nowadays, due to the limited capacity of batteries and long recharge times. Maximizing the driving range or the level of energy (state of charge of the battery) at destination leads to consider the main factors of energy consumption which are: vehicle weight, engine efficiency and consumption models, drive speed and acceleration, drive pattern, road grade, and payload.

Michael Schyns (ULg) [39] presents an algorithm based on an Ant Colony System to deal with a broad range of Dynamic Capacitated Vehicle Routing Problems with Time Windows, (partial) Split Delivery and Heterogeneous fleets (DVRPTWSD). Besides the traditional distance criterion, he addresses the important case of responsiveness. Responsiveness is defied here as completing a delivery as soon as possible, within the time window, so that the client or the truck may restart its activities. This is crucial for many production or service activities in different fields: express parcel deliveries, taxi services, Just in Time production, express repair services, medical care, petrol station replenishment, etc. The paper develops an interactive web-based solution to allow dispatchers to take new information into account in real-time. The algorithm and its parametrization were tested on real and artificial instances. The approach is first illustrated on a problem submitted by Liège Airport. The goal is to develop a decision system to optimize the journey of the refueling trucks. Some classical VRP benchmarks and extensions to more complex problems are then considered.

The School Bus Routing Problem (SBRP), a generalization of the well-known Vehicle Routing Problem, involves the routing, planning, and scheduling of public school bus transportation. The problem can be divided into several sub-problems, including bus stop selection, assigning students to buses, and determining the bus routes. In a paper by Joris Kinable, Frits Spieksma (KUL) en Greet Vanden Berghe (KUL), presented in [20] an exact branch-and-price framework for the SBRP. There is an emphasis on efficiency issues inherently related to column generation (CG). Experiments are conducted on a set of 128 SBRP instances. Many of these instances are solved optimally; for the remaining instances, strong lower bounds have been derived. Furthermore, better integer solutions were found for a number of instances reported in the literature. Both lower bounds computed on the optimum solution and stabilization added to the CG procedure significantly improved computation times.

Christof Defryn and Kenneth Sörensen (both University of Antwerp) further explored the idea of collaborative vehicle routing. Here, clients belonging to different logistic partners - forming a coalition - are served in a single logistic operation. First, they focused on the selective vehicle routing problem that has been defined in a collaborative environment. The operational plan, obtained by solving the underlying vehicle routing problem, is extended by including the partners' individual strategy and a cost allocation method. The resulting paper is submitted for publication.

Currently, the basic model and ideas developed for tackling collaborative vehicle routing problems are used and extended to a multi-objective environment, as it is possible that partners in the coalition have more than one (conflicting) objective. More specifically, the ANT/OR group at the University of Antwerp is now introducing the trade-off between distance travelled and time-window violation in a multi-partner environment. We take into account that a time-window violation might be perceived less important for one partner compared to the others. These results will again be linked to a cost allocation mechanism. This research was presented at the ORBEL conference in Mons and at the ALIO-EURO conference in Montevideo (Uruguay).

Christine Vanovermeire and Kenneth Sörensen (University of Antwerp) [52] discuss how flexibility (e.g., with respect to order delivery dates) can be awarded in a cost allocation mechanisms that is used in a collaborative distribution effort. The paper is accepted in the European Journal of Operational Research. A novel method, based on the Shapley Value, is developed for two-partner coalitions. C. Vanovermeire, Dries Vercruysse and Kenneth Sörensen [53] discuss the benefits and drawbacks of different cost allocation mechanisms in a horizontal logistics coalition

Christine Vanovermeire and Kenneth Sörensen [51] analyze a distribution problem in a collaborative environment. They examine whether the integration of a cost allocation mechanism in the operational planning algorithm is beneficial and show in a proof-of-concept implementation that this is feasible yet unpractical.

WP 2.2.4 Loading problems

Several participants in the project have continued investigating various types of loading problems arising in transportation management.

Distributors are faced with loading constraints in their route planning, e.g., multi-dimensional packing constraints, unloading sequence constraints, stability constraints and axle weight limits. Ignoring these constraints impairs planning and induces last-minute changes resulting in additional costs. Developing vehicle routing models incorporating loading constraints is critical to more efficient route planning. The last couple of years has seen a huge increase of contributions to this field of research with almost sixty percent of these being published after 2009. Hanne Pollaris, Kris Braekers, An Caris, Gerrit Janssens (UHasselt) and Sabine Limbourg (ULg) [36] overview the recent developments in the literature on all transport modes in which loading constraints play a key role (trucks, airplanes, ships, and automated guided vehicles), using a state-of-the-art classification scheme to identify the loading constraints considered in each article. They identify research gaps and opportunities for future research.

Hanne Pollaris, Kris Braekers, An Caris, Gerrit Janssens (UHasselt) and Sabine Limbourg (ULg) [35] have introduced and studied the capacitated vehicle routing problem with sequence-based pallet loading and axle weight constraints. It is the first time that axle weight restrictions are incorporated in a vehicle routing model. Their paper demonstrates that incorporating axle weight restrictions in a vehicle routing model is possible and necessary for a feasible route planning. This work was already announced in a previous report.

In September 2014, Thierry Pironet (ULg) has defended at the University of Liège a doctoral thesis entitled “Multi-period Stochastic Optimization Problems in Transportation Management“. His doctoral jury included several participants in the Comex project, namely, Yasmine Arda, Yves Crama, Sabine Limbourg, Michael Schyns (all at ULg) and Gerrit Janssens (UHas-

selt). The thesis develops a methodology to tackle multi-period decision problems involving stochastic forecasts and applies it to the field of transportation management. The methodology leads to an assessment of the value of the multi-period setting and of the stochastic information contained in the forecasts.

Clia Paquay, Michael Schyns and Sabine Limbourg (ULg) [33] have developed a mixed integer programming formulation for the three dimensional bin packing problem deriving from an air cargo application (that is, optimising the loading of boxes into containers). This work was already announced in a previous report.

WP 2.2.5 Dial-a-ride problem

Kris Braekers (UHasselt) has started developing heuristics for the heterogeneous dial-a-ride problem with multiple depots. He stayed for three months at the University of Vienna (with Sophie Parragh) to enhance his knowledge on this matter and to look for research opportunities. His first developments have been published in Transportation Research part B. He currently works with An Caris and doctoral student Yves Molenbruch (both UHasselt) on this matter, more specific on developing a multi-start local search heuristics for a bi-objective dial-a-ride problem.

WP 2.3 Operations Management

In this work package we study a number of applications in operations management. The applications serve as a valuator for the methodological development in the methodology packages and are selected from the range of applications in which the consortium has experience. Members of the IAP working in this domain are in the steering committee of the PATAT conference (York 2014) and the EURO/WATT working group on timetabling.

WP 2.3.1 Health care

We continued our work on personnel management in hospitals, in which we have been involved for over a decade. Several PhD students work on this subject specifically. Some handle problems of staffing and occupation of infrastructure, others study detailed rostering. In 2011 we reviewed the broad problem domain, building on our work in 2004 discussing the literature on nurse rostering. Apart from personnel management, problems such as bed planning, patient admission and operation quarter planning, as well as home care scheduling (a combination of vehicle routing and personnel-planning) pose challenging problems.

In practice nurse rostering problems are often too complex to be expressed through available academic models. Such models are not rich enough to represent the variegated nature of real world scenarios, and therefore have no practical relevance. Smet et al. (KUL) [40] focus on two particular modelling issues that require careful consideration in making academic nurse rostering approaches re-usable in a real world environment. First: introducing several complex problem characteristics, resulting in a rich, generic model. A detailed description is provided for researchers interested in using this new model. We also present a novel benchmark dataset based on this rich model. Second: the consideration of a consistent evaluation procedure that corresponds to realistic quality measurement. These contributions will enable faster implementation of academic nurse rostering achievements in real hospital environments. A suite

of hyper-heuristics is presented. These are capable of solving these rich personnel rostering problems using the presented evaluation procedures. Their performance is compared to that of another meta-heuristic. In [41], Smet et al. report on new results in the complexity of nurse rostering problems. Many papers in this domain start stating that the problem is NP-hard. They discuss some instances for which polynomial time algorithms can be found.

Komarudin et al. (KUL) [21] discuss the problem of fairness in personnel rostering. It defines a rule reflecting the idea of fairness and presents a heuristic for producing fair schedules according to this rule.

Nurse rostering problems as those defined in the nurse rostering competition can be solved efficiently using IP techniques, as this paper demonstrated by Toffolo et al. [47].

WP 2.3.2 Production scheduling

Decision making in production concerns building good responsive scheduling applications under dynamically changing conditions. Wauters et al. (KUL) continued studying the effects of incomplete information and uncertainty, while still providing near to optimal solutions. In this project we will build on this experience to investigate the possibilities of hybrid approaches in meeting all the aforementioned requirements.

Kinable, Wauters and Vanden Berghe (KUL) [19] discuss the problem of delivery of concrete to customers and show that it poses a hard to solve problem that combines scheduling and sequencing.

School bus routing can be considered a scheduling problem involving multiple components (scheduling and routing). This problem was studied by Kinable, Spieksma and Vanden Berghe (KUL) [20].

New approaches on the one dimensional cutting stock problem were studied in Garraffa et al. [12]. They present a new generalization of the one-dimensional cutting stock problem (1D-CSP) that considers cut losses that depend on the items' cutting sequence. It is shown that this generalization can still be solved approximately by standard 1D-CSP approaches. Furthermore, a pattern-based heuristic (denoted HSD) is resented that specifically considers sequence dependent cut losses (SDCL). A computational study shows that whenever some variability in SDCL occurs consideration of SDCL in the HSD heuristic is beneficial. Finally, two case studies illustrate the relevance of this new generalization.

WP 2.3.3 Other problems

Assigning scheduled tasks to a multi-skilled workforce is a known NP-complete problem with many applications in health care, services, logistics and manufacturing. Optimizing the use and composition of costly and scarce resources such as staff has major implications on any organization's health. Smet et al. (KUL) [42] introduce a new, versatile two-phase matheuristic approach to the shift minimization personnel task scheduling problem, which considers assigning tasks to a set of multi-skilled employees, whose working times have been determined beforehand. Computational results show that the new hybrid method is capable of finding, for the first time, optimal solutions for all benchmark instances from the literature, in very limited computation time. The influence of a set of problem instance features on the performance of different algorithms is investigated in order to discover what makes particular problem instances harder than others. These insights are useful when deciding on organizational policies

to better manage various operational aspects related to workforce. The empirical hardness results enable to generate hard problem instances. A set of new challenging instances is now available to the academic community.

Verstichel et al. (KUL) [55] introduce an integrated approach to solving the generalized lock scheduling problem. Three interrelated sub problems can be discerned: ship placement, chamber assignment and lockage operation scheduling. In their turn, these are closely related to the 2D bin packing problem, the assignment problem and the (parallel) machine scheduling problem respectively. In previous research, the three sub problems mentioned were considered separately, often using (heuristic) interaction between them to obtain better solutions. A mixed integer linear programming model is presented and applied to instances from both inland locks and locks in a tide independent port. The experiments show that small instances incorporating a wide range of real-life constraints can be solved to optimality.

In [54], the same team study the ship placement problem. This problem constitutes a daily challenge for planners in tide river harbours. In essence, it entails positioning a set of ships into as few lock chambers as possible while satisfying a number of general and specific placement constraints. These constraints make the ship placement problem different from traditional 2D bin packing. A mathematical formulation for the problem is presented. In addition, a decomposition model is developed which allows for computing optimal solutions in a reasonable time. A multi-order best fit heuristic for the ship placement problem is introduced, and its performance is compared with that of the left-right-left-back heuristic. Experiments on simulated and real-life instances show that the multi-order best fit heuristic beats the other heuristics by a landslide, while maintaining comparable calculation times. Finally, the new heuristic's optimality gap is small, while it clearly outperforms the exact approach with respect to calculation time.

The Traveling Umpire Problem (TUP), studied by Wauters, Van Malderen and Vanden Berghe (KUL) [56], is a challenging combinatorial optimization problem based on scheduling umpires for Major League Baseball. The TUP aims at assigning umpire crews to the games of a fixed tournament, minimizing the travel distance of the umpires. The present paper introduces two complementary heuristic solution approaches for the TUP. A new method called enhanced iterative deepening search with leaf node improvements (IDLI) generates schedules in several stages by subsequently considering parts of the problem. The second approach is a custom iterated local search algorithm (ILS) with a step counting hill climbing acceptance criterion. IDLI generates new best solutions for many small and medium sized benchmark instances. ILS produces significant improvements for the largest benchmark instances. In addition, the article introduces a new decomposition methodology for generating lower bounds, which improves all known lower bounds for the benchmark instances.

Vancroonenburg et al. (KUL) [49] introduce a mixed integer linear programming model as a decision support tool for air cargo load planning. The main objective for the model is to find the most profitable selection from a set of cargo to be loaded on an aircraft. The secondary objective is to minimize the deviation between the aircraft?s center of gravity, and a known target value so as to reduce fuel consumption and improve stability. The model is subject to a large number of constraints that ensure structural integrity and stability of the aircraft, as well as the safety of the cargo and crew. A set of additional constraints guarantees safe and efficient loading and unloading. Experimental results on real-life data show that the model outperforms human expert planners on both objectives, while remaining computationally fast enough for interactive use. This advocates the use of such a decision support model for all air cargo load

planning.

The study by Misir, Smet, and Vanden Berghe (KUL) [26] investigates the performance of heuristics while solving problems with routing and rostering characteristics. The target problems include scheduling and routing home care, security and maintenance personnel. In analyzing the behavior of the heuristics and determining the requirements for solving the aforementioned problems, the winning hyper-heuristic from the First International Cross-domain Heuristic Search Challenge (CHeSC 2011) is employed. The completely new application of a hyper-heuristic as an analysis tool offers promising perspectives for supporting dedicated heuristic development. The experimental results reveal that different low-level heuristics perform better on different problems and that their performance varies during a search process. The following characteristics affect the performance of the heuristics: the planning horizon, the number of activities and lastly the number of resources. The body of this paper details both these characteristics and also discusses the required features for embedding in an algorithm to solve problems particularly with a vehicle routing component.

J. Janssens (UA), J. Van den Bergh (UA), K. Sörensen (UA) and D. Cattrysse (KUL) investigate a multi-objective vehicle routing problem for courier companies. They study how to go from a tactical plan to an operational plan by evaluating zones instead of individual clients. They developed a variable neighborhood tabu search to minimize total distance travailed and balance workload between drivers, reallocating as little micro-zones as possible. It was completed in 2014 and published in [15].

L. Talarico (UA), K Sörensen (UA) and Frank Meisel (University of Kiel) study a special type of routing problem for ambulances in a disaster response scenario in which a large number of injured people require medical aid at the same time. The ambulances are used to carry medical personnel and patients. We distinguish two groups of patients: slightly injured people who can be assisted directly in the field, and seriously injured people who have to be brought to hospitals. This was completed in 2014 and published in [45]. This research has been presented at the 20th IFORS Conference in Barcelona, Spain.

L Talarico (UA), K Sörensen (UA), J. Springael (UA) and G. Reniers (UA) developed a multi-modal security-transportation model to allocate security resources within a chemical supply chain. The decision model is based on game theory and it can be employed to organize intelligence capabilities aimed at preventing terrorist attacks, avoiding (possibly huge) human and economic losses. This research has been presented at the XXIV European Safety and Reliability Conference (ESREL) in Wroclaw, Poland.

A. Caris (UHasselt), S. Limbourg (ULg), C. Macharis (VUB), T. Van Lier (VUB) and M. Cools (ULg) have identified research opportunities which will enable the further integration of inland waterway transport in the intermodal supply chain. This work was already announced in a previous report. It was completed in 2014 and published as [7].

Santos, Limbourg and Carreira [38] discuss the impact of three freight transport policies aiming to promote railroad intermodal transport in Europe, and examine the case of Belgium as a testing ground. These policies consist in subsidizing intermodal transport operations (such as in Belgium, to stimulate rail transport), internalizing external costs (as recommended by the European Union in order to foster cleaner modes), and adopting a system perspective when optimizing the location of inland intermodal terminals. The study proposes an innovative mixed integer intermodal freight location-allocation model based on hub-location theory and deals with non-linear transport costs in order to replicate economies of distance. The analysis suggests that subsidizing has a significant impact on the volumes transported by intermodal trans-

port, and, to a lesser extent, that optimizing terminal location increases the competitiveness of intermodal transport. The assumption, however, is that internalizing external costs can negatively impact the promotion of intermodality. This finding indicates that innovative last-mile transports are needed in order to reduce the external impacts of drayage operations.

Expanding variety and the number of offered products is attractive for a firm to fit customer needs. Nevertheless, the greater complexity and the proliferation of stock-keeping units (SKUs) without substantial differentiation may not substantially improve customer satisfaction while raising costs. Based on the principle that the product-line size involves operational implications and particularly manufacturing and holding costs, Tanguy Kegelart (UCL) and Mathieu Van Vyve (UCL) develop in [18] a mixed-integer nonlinear mathematical program (MINLP) to support efficient product portfolio reductions. Basically, the fixed costs elimination and the risk-pooling effects must balance the demand contraction due to customer dissatisfaction. Off-the-shelve Mixed-Integer Quadratic Problem (MIQP) solver provides optimal solution to the proposed conic quadratic reformulation, and a real-life industrial case illustrates the program and the algorithm efficiency. Findings show that our mathematical programming subject to various assumptions and estimations is efficient to rationalize portfolios up to at least 400 SKUs.

WP 2.4 Bio-informatics

2.4.1 Parsimonious Loss of Heterozygosity Problem

The Parsimonious Loss of Heterozygosity Problem (PLOHP) is a NP-hard combinatorial optimization problem arising in computational biology. The problem consists of finding a minimum cost clique covering in a particular kind of interval graph called Max-Point Tolerance Graph (MPTG). The optimal solution to an instance of the PLOHP proves of fundamental support in genome-wide association studies as it allows the association of major human diseases with chromosomic regions from patients that underwent loss of heterozygosity events. An integer linear programming formulation for the PLOHP based on column generation is proposed by L. Porretta (ULB/GOM), D. Catanzaro (UCL), Bjarni V. Halldórssone and B. Fortz (ULB/GOM) [37]. They have introduced a number of preprocessing techniques reduce the size of a given instance of the problem and presented decomposition strategies to divide a reduced instance into independent subproblems of even smaller size. They have developed a new efficient algorithm to find maximum node-weighted cliques in MPTGs. Moreover, they have implemented this algorithm in a Branch-and-Price algorithm for the PLOHP, whose computational performance is 10-30 time faster than the previous approach described in the literature.

2.4.2 ALU polymorphisms

ALU (Arthrobacter luteus) elements are a common source of mutation in humans, but such mutations are often confined to non-coding regions where they have little discernible impact on the bearer. However, the generated variation can be used in studies of the movement and ancestry of human populations, and the mutagenic effect of ALU and retrotransposons in general has played a major role in the recent evolution of the human genome. There are also a number of cases where ALU insertions or deletions are associated with specific effects in humans. Even if, ALU polymorphisms are some of the most common polymorphisms in the genome,

yet few methods have been developed for their detection. Since summer 2014, Bernard Fortz (ULB/GOM) and Luciano Porretta (ULB/GOM) are working on developing an exact approach for the the detection of ALU insertions in the DNA which will results in a tool able to estimate ALU genetic variations.

Finaly, note that the problems related to network topology discovery described in WP2.1 have also applications in the reconstruction of phylogenetic trees.

WP 2.5 Economics

2.5.1. Pricing problems

Several COMEX researchers are investigating variants of *pricing problems*.

Using (combinatorial) auctions to arrive at prices that achieving a particular allocation of goods satisfying certain criteria, is a fundamental problem in economics. There is a abundant theory on this matter, however, in the case of combinatorial auctions, there are not so many case-studies. Goossens et al. [13] describe a combinatorial auction that took place in May 2011. Jointly organized with housing corporation Stadgenoot, this culminated in the first combinatorial auction for housing space in a newly erected multistory building in Amsterdam in the Netherlands. The primary goal was to allocate space based on the preferences of many potential users. The resulting allocation included space for restaurants, boutiques, a dentist, and residential users. The auction was designed to maximize total rent for Stadgenoot while complying with municipal and building regulations. This design was based on laboratory experiments that gave guidance on choices regarding, for example, pricing, feedback, and activity rules.

It is well-known that a market equilibrium with uniform prices often does not exist in non-convex day-ahead electricity auctions. Mehdi Madani (UCL) and Mathieu Van Vyve (UCL) consider in [24] the case of the non-convex, uniform price Pan-European day-ahead electricity market ”PCR” (Price Coupling of Regions), with non-convexities arising from so-called complex and block orders. Extending previous results, they propose a new primal-dual framework for these auctions, which has applications in both economic analysis and algorithm design. The contribution here is threefold. First, from the algorithmic point of view, they give a non-trivial exact (i.e. not approximate) linearization of a non-convex ’minimum income condition’ that must hold for complex orders arising from the Spanish market, avoiding the introduction of any auxiliary variables, and allowing them to solve market clearing instances involving most of the bidding products proposed in PCR using off-the-shelf MIP solvers. Second, from the economic analysis point of view, they give the first MILP formulations of optimization problems such as the maximization of the traded volume, or the minimization of opportunity costs of paradoxically rejected block bids. We first show on a toy example that these two objectives are distinct from maximizing welfare. They also recover directly a previously noted property of an alternative market model. Third, they provide numerical experiments on realistic large-scale instances. They illustrate the efficiency of the approach, as well as the economics trade-offs that may occur in practice. A short version of this work appeared in [23] the proceedings of 11th International Conference on the European Energy Market (EEM) 2014.

E. Marcotte (ULB/GOM) worked on the design of mechanisms that could reduce congestion in the European airspace through the imposition of tariffs and subsidies to commercial airline carriers. He developed two different mechanisms that were modelized using mixed-

integer programming. Both mechanisms were tested on small examples as proofs of concept, and the most successful of the two was implemented on a country-sized portion of the full European network using historical flight data. The numerical efficiency of the model was tested and found to be acceptable, but unlikely to remains so when scaling up to the full network. To address this issue, more appropriate implementation are currently being developed.

B. Fortz (ULB/GOM), M. Labbé (ULB/GOM) and A. Violin (ULB/GOM) studied the Network Pricing Problem with Connected Toll Arcs. Consider a network where there are two types of arcs: a subset of arcs is owned by a company imposing tolls for using them, and a subset of remaining arcs which are toll-free. Furthermore, toll arcs are connected such that they constitute a single path, as it occurs for instance in a highway network. The company is willing to maximise the revenue from tolls, whilst users seek for their minimum cost path between their origin and destination. This problem can be modeled in a bilevel programming framework and proved to be strongly NP-hard.

Fortz, Labbé and A. Violin proposed a Dantzig-Wolfe reformulation for this problem, and showed that the linear relaxation is stronger than the mixed-integer formulation from the literature, and easily solvable. They then extended this framework: more advanced techniques have been included in the column generation algorithm, as initialisation alternatives, stabilisation of dual variables values and early stopping criteria. Furthermore, they proposed a full Branch-and-Price scheme to solve the integer problem, with an ad-hoc branching algorithm using pseudo-costs to guide the choices. Some rounding heuristics have been also investigated to improve the primal bound during the branching. Finally, some efficient valid inequalities from the literature have been reformulated and included in the Branch-and-Cut-and-Price scheme. Numerical experiments, on both random and realistic instances, have been run under the SCIP framework.

Within a collaboration with ULB/IRIDIA, both the column generation and the Branch-and-Cut-and-Price algorithms were tuned with an automatic tuner of parameters (irace), to find the best performing configurations. There was a large difference in the performance of the algorithms depending on the configuration chosen, and given the large number of parameters to be set, using an automatic tuner revealed to be very useful.

C. Casorràn-Amilburu (ULB/GOM), B. Fortz (ULB/GOM), M. Labbé (ULB/GOM) and F. Ordóñez studied the polyhedral aspects of formulations used to solve Stackelberg and Stackelberg Security Games. They established a ranking between these formulations, and provided formulations with a tighter continuous relaxation for the Bayesian case. Thorough computational experiments have confirmed the theoretical findings. The formulations respond significantly better in terms of running time, number of nodes in the branch-and-bound tree and gap between the optimal solution and the solution at the root node.

Restricting the original problem to a single type of follower game has allowed to find convex hull-defining formulations both for the General Stackelberg Game and for the Security Stackelberg Game when the leader faces one follower type.

They also bridged the gap between the General Stackelberg formulation and the Stackelberg Security formulation. Having understood how the payoff structures relate and the precise meaning of the variables used, they managed to establish a projection result linking both formulations.

2.5.2. Decision-making models

Revealed preferences

An interesting topic in computational economics is the complexity of testing different axioms of revealed preference, which relate the act of purchasing a bundle of goods to expressing a preference of the acquired bundle over other bundles. This topic has been investigated for a number of years by a joint team involving IAP researchers as well as several other researchers at KULAK and ULB.

Probably, the most well-known axiom is the so-called Generalized Axiom of Revealed Preferences, known as GARP. In a recent note, Talla Nobibon et al. [28] show how to speed up testing GARP to $O(n^2)$ (where n refers the number of observations). They also give lower bounds on testing other axioms such as the Weak Axiom of Revealed Preferences (WARP) and the Strong Axiom of Revealed Preferences (SARP).

It is well-known that, for single-member households, WARP and SARP are equivalent when there are only two goods. In a paper by Smeulders et al. [44], this result is extended towards households consisting of L members, for which the authors introduce the concepts L-WARP and L-SARP. It is demonstrated that L-WARP and L-SARP are not equivalent if there are at least $L+1$ goods. However, it can also be shown that L-WARP and L-SARP do become equivalent for the restricted "labor supply" setting where each single good is exclusively assigned to a different household member, i.e., in a setting where L (out of $L+1$) goods are exclusive.

Smeulders et al. [43] provide results on the computational complexity of so-called goodness-of-fit measures (i.e., Afriat's efficiency index, Varian's efficiency vector-index, and the Houtman-Maks index). Such measures are associated with several revealed preference axioms (i.e., WARP, SARP, GARP, and HARP), and indicate to what extent a particular axiom is violated. The results explain the computational difficulties that have been observed in literature when computing these indices. The NP-hardness results are obtained by reductions from the independent set problem. Also, an exact, polynomial-time, algorithm for finding Afriat's efficiency index is presented.

Collaborative decisions

Game-theoretic models can be used to support decisions in transportation management.

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5 Network organisation and operation

The project is a collaboration between seven Belgian research groups from six different universities, and two international partners from the Netherlands and Canada. The project coordinator it responsible for the day-to-day coordination of the project. He is also so the main interface between the network and the funding agency (Belgian Federal Science Policy Office). He monitors the project planning and progress, consolidates the annual reports, and is responsible for the communication between the partners and for the dissemination of information provided by the partners.

The importance given by the project to organization, management, and dissemination is reflected by the workpackages WP 0.1 to WP 0.3, led by the project coordinator. We refer to Section 4 of this report for details on the achievements in these workpackages.

For each workpackage, the workpackage coordinator is responsible for coordinating the research, and reporting to the project coordinator of any sensible matter related to the activities of the workpackage itself.

The steering committee of the project is formed by the local co-ordinators of all project partners, and be chaired by the project coordinator. The steering committee decides about the high level management issues, including training of researchers, scientific, financial, planning, and control matters. It supervises the project as a whole and is responsible to resolve conflicts and disputes in case they should arise.

The steering committee met two times during the first year of the projetc: during the annual meeting at ULB (November 19, 2013) and during the COMEX Belgian Workshop on Mathematical Optimization in La-Roche-en-Ardenne (April 24-25, 2014).

Several scientific and networking joint meetings took place during the year. These are reported in Subsection 3.1.

6 Publications

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