Contents

Welcome to ORBEL31, welcome to Brussels!

Dear participant,

It is with great pleasure that we welcome you to Brussels for the 31st edition of the Belgian Conference on Operations Research. It is the first time that ORBEL gathers at the Faculty of Economics and Business of KU Leuven, campus Brussels.

The Faculty of Economics and Business of KU Leuven has undergone profound changes over the past two years, changes that created many opportunities. The school evolved from two to four campuses, doubled the size of its student body to 8,000 and its staff to 750, broadened its portfolio with especially internationally oriented programs, and acquired the EQUIS accreditation. Today, the School capitalizes on the full potential of a multi-campus organization with locations in the oldest university town of the low countries (Leuven), in the industrial heart of Flanders and one of the most advanced logistics centers in Europe (Antwerp), in the financial district of Belgium and the political capital of Europe (Brussels) and in the Euro metropole close to Lille (Kortrijk).

The expansion allows us to better cater to the diversified demand from corporate world and policy bodies by broadening our program portfolio along a continuum ranging from a solid emphasis on analytical rigor (e.g. Business Engineering, Information Systems Engineering, Financial and Actuarial Engineering) to more inductive evidence-based and practice-driven programs (e.g. Business Administration, International Business Economics and Management).

The development of a campus in Brussels, with English medium degrees in Business Administration and Business Engineering, increases the attractiveness for international students and partner institutions. Over the last year, the number of partners has been extended to almost 200.

The internationalization of our school is also supported by its EQUIS accreditation. With this accreditation, the School now belongs to an elite group of just 150 accredited schools in 40 countries. The EQUIS quality label is a visible recognition of the school's achievements in education, research, faculty management, corporate connections and internationalization.

We really hope that you will have a splendid time at the Faculty of Economics and Business of KU Leuven in Brussels and this both on a scientific -with more than 80 contributions from OR research teams in Belgium and abroad- as well as a social level.

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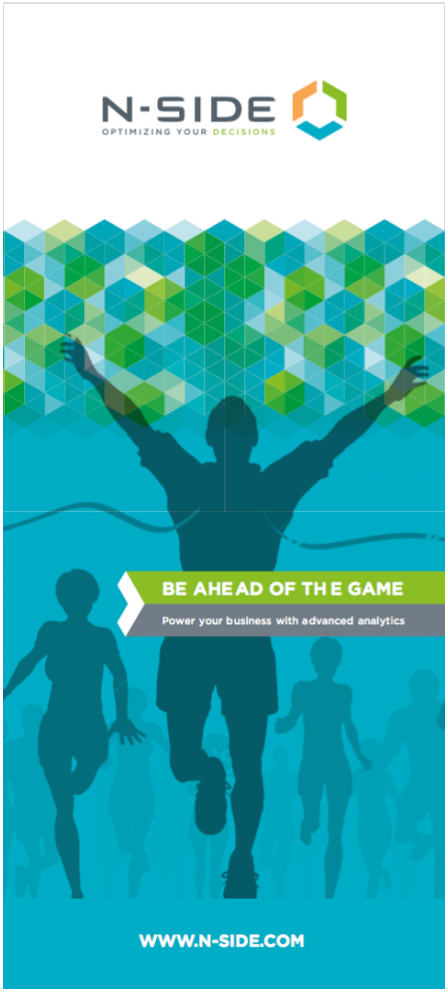
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Plenary talks

James J. Cochran

University of Alabama

James J. Cochran is Professor of Statistics, Rogers-Spivey Faculty Fellow, and Head of the Department of Information Systems, Statistics and Management Science at the University of Alabama. He earned a PhD in Statistics from the University of Cincinnati in 1997, and he has been a Visiting Scholar with Stanford University, the University of South Africa, the Universidad de Talca, and Pôle Universitaire Léonard De Vinci. Professor Cochran was a founding co-chair of Statistics Without Borders and a member of the founding committee for INFORMS Pro Bono Analytics initiative. He established INFORMS' Teaching Effectiveness Colloquium series and annual case competition. In 2005 Professor Cochran established the International Education Workshop series; through this series colloquia have been held in Uruguay, South Africa, Colombia, Tanzania, Argentina, Kenya, India, Fiji, Croatia, Nepal, Cuba, and Mongolia (with plans for upcoming colloquia in Moldova, Madagascar, and Romania). In 2008 he organized the 2008 ORPA Conference on Using Operations Research to Address Urban Transport and Water Resource Management Issues in Africa. Professor Cochran is founding Editor-in-Chief of the Wiley Encyclopedia of Operations Research and the Management Sciences and the Wiley Series in Operations Research and Management Science as well as the forthcoming Guide to the Analytics Body of Knowledge. He has published over forty research articles and a dozen book chapters, and he is coauthor of seven textbooks in statistics, operations research, and analytics. He has served as a consultant to a wide variety of corporations, government agencies, and not-for-profit organizations around the world. He served as Editor-in-Chief of INFORMS Transactions on Education and serves on the boards of several journals. In 2006 Professor Cochran was elected to the International Statistics Institute, in 2008 he received the INFORMS Prize for the Teaching of OR/MS Practice, in 2010 he received the Mu Sigma Rho Statistical Education Award, and in 2011 he was named a Fellow of the American Statistical Association. In 2014 he became the 86th recipient of the American Statistical Association's Founders Award, and in 2015 he received the Karl E. Peace Award for outstanding statistical contributions for the betterment of society.

Active learning in the modern Operations Research classroom: reengaging and reenergizing your students and their instructor!

We in the operations research community understand that Analytics (and specifically OR and Statistics) are inherently interesting, relevant, important, and enjoyable disciplines - unfortunately many of our students (particularly those in introductory Analytics courses) don't seem to share this understanding with us! So how do Analytics instructors help students appreciate that Analytics is interesting and relevant and important and enjoyable? Professor Cochran discusses several classroom cases and active learning exercises he has developed and regularly uses

to accomplish this goal when teaching introductory Analytics courses. Throughout this session Professor Cochran will emphasize his points with live demonstrations and discussions of several interesting and novel active learning exercises and cases. Card tricks, classroom versions of television game shows, and a teaching case with integrated active learning will be featured. Because many of these exercises are easily transferable across topics, instructor/classroom styles, cultures, national borders, institutions, faculties, programs, and class sizes, it is very likely you will walk away from this session with ideas on how to improve your own teaching (indeed, Professor Cochran will be very disappointed if you don't!). Be prepared - audience participation is an integral part of this session, and Professor Cochran may call on you during the session!

Marco Lübbecke

RWTH Aachen University

Marco Lübbecke is a professor and chair of operations research at the RWTH Aachen University, Germany. He is interested in computational integer programming, and has a research focus on decomposition-based methods (e.g., Dantzig-Wolfe reformulation, column generation, and branch-and-price) applied to large-scale and complex optimization problems. Many of these directly come from industrial applications in production, logistics, transport, energy, politics, healthcare, and education. He is currently Vice President for Information Technology in the INFORMS board of directors.

Branch-and-price

Many practical optimization problems can be formulated with models with an enormous amount of variables. These variables typically represent combinatorial objects like subsets, configurations, or permutations. We are able to solve such models, even to optimality, because variables can be dynamically generated via column generation. Embedded in branch-and-bound we obtain branch-and-price. Formally, one may arrive at such models via a Dantzig-Wolfe refomulation of some integer program. One benefit of the reformulation is a potentially stronger relaxation. We describe efforts to develop a generic solver that is able to automatically perform the reformulation, and solve the latter by branch-and-price. An important part of this is to detect exploitable model structure, where we present our state of knowledge and identify blind spots where more research is needed.

ORBEL Award talks

Benonie Carette: Berth allocation in a stochastic environment

Liesa D'haeseleer: Central allocation of pupils to schools

Ben Hermans: Project scheduling in stealth mode

Sarah Itani: Statistical analysis of medical data using a multilevel approach

Abstracts

Routing - efficient and simple

F. Arnold
University of Antwerp, Operations Research Group
e-mail : florian.arnold@uantwerpen.be

K. Sörensen
University of Antwerp, Operations Research Group

Routing problems are among the widest-studied area in combinatorial optimization. Their popularity arises from their complexity and applicability in practice. Due to the problem complexity, a major research stream on heuristics has evolved, to find high-quality solutions in a feasible time. The success of heuristics has triggered a race for ever better and faster solution methods.

This race has changed the research focus heavily towards the metrics accuracy and speed. In exaggerated words, a heuristic has to produce excellent solutions on benchmark instances in order to be published. As a consequence, many state-of-the-art heuristics have become extremely complex, both in the design and the amount of parameter that they involve. This complexity leads to two disadvantages. Firstly, it becomes more difficult to study the impact of the individual components and thereby generalize findings and generate deeper understanding of why exactly the heuristic works well. Secondly, the heuristics can barely be reimplemented (to validate results or reuse it in another context). Even though this complexity of modern heuristics might be a necessary evil to obtain outstanding solutions, simplicity and flexibility should also be essential attributes of good heuristics. Simple and flexible heuristics are easier to understand in detail and can be more readily applied to a variety of problems.

In the following work, we address the question, whether it is possible to get the best of both worlds. Can we design a heuristic that produces excellent solutions in a short time and is, yet, simple and flexible? Our conceptual design is driven by two components. Firstly, we focus heavily on a well-implemented and efficient local search. We use few but powerful local search operators that have been proven and tested many times. Secondly, we strive to make the local search even more effective by guiding it through problem-specific knowledge.

As a result, we demonstrate that a simply-designed metaheuristic based almost entirely on local search is sufficient to compete with the best heuristics on various benchmark sets for the standard Vehicle Routing Problem. Moreover, we can easily extend the heuristic framework to other variants of routing problems, like the routing from multiple depots and routing with route-constraints.

Insights of Flexible Line Planning

Elina Avila Ordóñez
KU Leuven, Leuven Mobility Research Centre - CIB.
Celestijnenlaan 300, Box 2422, BE-3001, Leuven - Belgium,
e-mail: elina.avilao@ucuenca.edu.ec

Pieter Vansteenwegen
KU Leuven, Leuven Mobility Research Centre - CIB.
Celestijnenlaan 300, Box 2422, BE-3001, Leuven - Belgium,

Chris M. J. Tampère
KU Leuven, Leuven Mobility Research Centre - CIB.
Celestijnenlaan 300, Box 2422, BE-3001, Leuven - Belgium,

Several means of transport offer an alternative to move persons from one place to another. Whether public or private, these means need to be designed. In this study, an innovative approach is presented to design and operate a bus service considering the dynamics of an actual road network during operations.

A line planning is a set of bus lines [1]. Each line starts at an origin point, visits a set of intermediate bus stops and reaches a destination, all of that according to a time schedule. But, when an exceptional situation occurs (traffic jams, the demand at certain points raises, etc.) the service's performance is affected. This is the obvious result of planning a service for a particular situation without considering that the conditions in a network change constantly while the service is operating. In this work, a set of insights to design a so called "Flexible" Line Planning for bus services is determined. A Flexible Line Planning contains a set of temporal or permanent changes in the line planning which can decrease the effect of exceptional situations in travel times or demand. Indeed, this assumes that in the future some bus lines can change their routes during operations in order to improve the performance of the service.

To this end, a methodology to identify and apply useful permanent and/or temporal changes in line planning is proposed and tested. A well performing genetic algorithm [2] was developed for the line planning problem. The objective is always minimizing the total travel time of the passengers. The fleet size and line length of the lines are fixed and act as budget constraints from the operator side. A sensitivity analysis, based on alternative line plans for exceptional situations, led to three insights. The insights are formulated and lead to permanent changes to the line planning, thus also for the normal situation, and temporal changes that can be applied during operations.A sensitivity analysis, based on alternative line plans for exceptional situations, led to three insights. Insight 1 is about how adding nodes, splitting or joining lines, as temporal or permanent changes, are

useful in case of peak demand. Insight 2 uses alternative paths and express lines to decrease the total travel time in scenarios with some congested links. Finally, insight 3 considers second best paths during planning and operations of a bus service.

The adapted line plans, presented in this work, illustrate how a flexible line plan can be helpful to reduce the negative impact of exceptional situations.

Mandl's network [3], a benchmark network of 15 nodes, was used as a proof of concept of the methodology. Consistent and useful results were found. Currently, a real case study, based on the city of Cuenca (Ecuador), with around 300 nodes is used to determine under which conditions flexible line plans can be beneficial in realistic situations.

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Stochastic Constraint Programming with And-Or Branch-and-Bound

Behrouz Babaki*, Tias Guns*+, Luc De Raedt*
* KU Leuven, Belgium
cs.kuleuven.be
+ Vrije Universiteit Brussel, Belgium
tias.guns@vub.ac.be

Complex multi-stage decision making problems often involve uncertainty, for example regarding demand or processing times. Such problems requires one to make *decisions* under *constraints* while taking into account the *uncertainty* of the environment.

Each of these aspects has intensively been studied by different communities within operations research and artificial intelligence. Indeed, constraint programming has focussed on solving constraint satisfaction problems; in stochastic optimization a common approach is to do scenario-based optimization; the field of uncertainty in artificial intelligence investigates reasoning over probabilistic graphical models; while planning is concerned with taking actions and making decisions. For each of these problems, advanced solutions have been developed and solvers exist that can tackle substantial problems. But today, there is a growing awareness that in many real-life applications, these aspects cannot be addressed in isolation.

This has motivated researchers to look at integrated approaches. For instance, [Mateescu and Dechter, 2008] have integrated constraint programming and probabilistic graphical models (but do not deal with decisions and utilities); and influence diagrams [Jensen et al., 1994] integrate probabilistic graphical models with decision theory (but do not handle constraints), while stochastic constraint programming [Walsh, 2002, Tarim et al., 2006] covers all three aspects as it extends constraint programming with decision-making under uncertainty with arbitrary complex constraints. However, it does not yet support standard probabilistic techniques from the graphical model community. It is well-known in probabilistic graphical models that factorizing the joint probability distribution is beneficial for modeling, inference and for learning. Currently, either trivial factorizations, assuming either that all random variables are marginally independent [Walsh, 2002], are used or the joint is approximated with a number of fixed scenarios [Tarim et al., 2006]).

What is lacking is the ability to combine this with arbitrary probabilistic models directly. We investigate how a probabilistic inference engine can be integrated into standard constraint solvers. The key contribution of our approach is that we integrate state-of-the art probabilistic inference techniques into stochastic constraint programming. The result is a solver that tightly integrates constraint

programming, decision making and probabilistic inference. At the technical level, our contributions are:

- We support the use of factorized joint probability distributions (as in Bayesian networks) and integrate state-of-the-art inference engines for such graphical models in our stochastic constraint programming approach. We therefore call our technique Factored Stochastic Constraint Programming (FSCP).
- We build upon (stochastic) constraint programming techniques, in particular, we use a generic constraint solver for constrained branch-and-bound search over an AND-OR tree.
- We develop a novel bound for expected utility, by performing a depth-bounded search over the random variables. Key is that we use probabilistic inference to compute marginal probabilities of variables at that depth, and interval arithmetic to get a tight bound on the utility.

The resulting system searches over the AND-OR search tree directly, and we investigate tight bounds on the expected utility objective. This significantly improves search efficiency and outperforms scenario-based methods that ground out the possible worlds.

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Teaching linear programming through a Game of Thrones adventure

Jeroen Beliën
KU Leuven, Department of Information Management, Modeling and Simulation
e-mail: jeroen.belien@kuleuven.be

Liesje De Boeck
KU Leuven, Department of Information Management, Modeling and Simulation
e-mail: liesje.deboeck@kuleuven.be

Jens Vermeir
DHL aviation NV
e-mail: Jens.vermeir@gmail.com

1 Introduction

Educational games have shown to be effective in increasing students' motivation for linear programming (LP) modeling ([1], [2]). This paper presents an educational game built entirely around the popular HBO series Game of Thrones. By isolating standard LP modeling exercises from classic applications in business education and placing them in a totally different context, we hope to increase the students' commitment and motivation for finding correct formulations and optimal solutions for various LP modeling exercises.

2 The game

In the Game of Thrones optimization game, the student takes on the role of a miner's son and encounters various important leading characters from the television series. Every encounter involves formulating and solving a linear programming problem correctly before being allowed to move on to the next one. This provides the student with clear short term goals, which enhances the game play and thus the interest for the game. The time in which a student finishes the game is recorded and eventually used to calculate the rank out of five possible positions in the king's small council.

Every student follows the same story line and is challenged with the following five standard LP modeling problems which are included in many introductory linear programming handbooks (e.g., [3]): a blending problem, a transportation problem, a production process problem, a static work-scheduling problem and a multi-period production planning problem. Additionally, one of the characters

presents a question that boils down to a sensitivity analysis exercise. The only difference with more traditional LP formulation exercises is that the in-game problems have the Game of Thrones theme. For instance, the blending problem involves producing poisons to kill enemies instead of the classic oil production problems. One needs to optimize the movement of troops on the battlefield instead of the classic transportation problems of minimizing the cost of distributing goods to customers.

The game is completely developed in Microsoft Excel using Visual Basic for Applications. Since all data are provided in Excel, the Excel solver tool is the most natural approach for finding optimal solutions, but other solvers could be used as well. For instance, IBM's CPLEX Optimization Studio can easily read in spreadsheet data. As such, the game can also serve as a tool to gain insights in how spreadsheet models translate to algebraic models and vice versa.

3 Classroom experience

The Game of Thrones quest for optimality has been used for teaching LP modeling in an introductory course of linear programming for 2nd bachelor business engineering students at KU Leuven Campus Brussels in the academic years 2015-2016 and 2016-2017. In 2015-2016 the game was used as a repetition exercise during a 2-hour PC room session in the last class of the semester. We opted for an in-class exercise as this stimulates competition among students. The faster a student finds the correct solutions, the higher the final rank in the king's council. We noticed, however, that students need more time than 2 hours to successfully complete all six challenges. Therefore, in 2016-2017, the game was given as a homework assignment, enabling all students to experience the adventure at their own pace at the cost of losing the competitive aspect of playing simultaneously against other students. In the assignment, students were required to develop both a spreadsheet model and an algebraic model (to be solved using CPLEX) for each in-game optimization problem. In 2015-2016 the game was assessed by our students through a formal questionnaire revealing that the game increased the students' motivation and indicating a strong surplus value for the LP course.

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MCDA in environmental assessment contexts

Valérie Brison
Université de Mons, Faculté Polytechnique
e-mail : valerie.brison@umons.ac.be

Marc Pirlot
Université de Mons, Faculté Polytechnique
e-mail : marc.pirlot@umons.ac.be

Multi-criteria decision aiding can be useful in environmental studies aiming to support decision making on environmental policies. For example, the *ESNET (Ecosystemic Services NETworks)* project aims at analyzing different scenarios of land-use in the horizon 2040 and their impacts on ecosystemic services (i.e., services provided by Nature). In this project, we have maps that represent the evaluation of the pixels on the considered services. We first want to aggregate the pixels evaluation at a commune level. Then, we have to aggregate the services into packages in a way that depends on the type of area considered (rural, forest or peri-urban area). We have several rules given by experts to assign the communes of the region under study to a category representing the quality of the package of ecosystemic services. Finally, we have to compare maps representing the state of the region under different scenarios. We shall present various multi-criteria models that were developed for helping to structure and solve such problems. The conditions of applicability of such models have been studied in a formal way (including axiomatics).

Preconditioning linear systems from deformable 3D medical image registration using tensor train format

Justin Buhendwa Ny.
Université de Namur, Département des Mathématiques
e-mail : justin.buhendwa@unamur.be
Annick Sartenaer
Université de Namur, Département des Mathématiques

In medical image analysis, deformable 3D image registration takes a relatively long time, especially for non-parametric transformations, for which the computing time may be quite troublesome and not even feasible for some clinical applications. Modeled as a variational problem, this registration problem needs to solve a sequence of linear systems during the optimization process. Much of the time is spent in the solution of these linear systems. Indeed, although these systems are sparse and structured, they are very large and ill conditioned. In this talk, we present and study a preconditioning technique to accelerate the solution of these linear systems using tensor train format. Appropriate preconditioners in tensor train format offer a good compromise between complexity and precision.

Optimizing buffer times and supplements in passenger robust timetabling

S. Burggraeve
KU Leuven, Leuven Mobility Research Centre
e-mail: sofie.burggraeve@kuleuven.be

P. Vansteenwegen
KU Leuven, Leuven Mobility Research Centre
e-mail: pieter.vansteenwegen@kuleuven.be

We propose an innovative approach to build a timetable and routing plan from scratch for large and complex railway station areas. In railway planning for passengers, short and reliable passenger travel times are a must. Therefore, our objective is to directly optimize the passenger robustness, which means that the passenger travel time in practice in case of frequently occurring small delays, is minimized. There are three main indicators that influence the passenger robustness. The first indicator is *the capacity usage of switches* in the network. The more trains are planned to use a certain switch or platform, the more trains can be affected by a delay of one of the other trains that use that shared switch or platform. The second indicator is *the buffer time* between every pair of trains on a shared switch or platform. A train reserves (releases) an infrastructure element from the moment it passes the signal the closest before (after) that infrastructure element with the head (tail) of the train. The buffer time is the time between the release time of the first train and the reservation time of the second train on the shared infrastructure. The smaller the buffer time between two trains on the shared infrastructure, the higher the probability on delay propagation between these two trains. The third indicator are *the supplements* added to the minimum necessary running and dwell times of the trains. Without supplements, a train can never absorb its delays. Supplements are necessary to be able to catch up to the original schedule in case of a delay. Note that supplements increase the planned travel time of trains and passengers, while buffer times only affect the planned passenger travel times in case of transfers.

In practice, usually 5% up to 7% of the running and dwell times are added as a supplement. Since supplements increase the planned travel time and decrease the available capacity, our objective is to schedule these supplements with more care. The authors in [4] allocate running time supplements to a single train on a number of consecutive trips. As a result of the many interactions between trains in complex station areas this approach is not straightforwardly applicable for this input. The authors of [1] combine timetabling on the macroscopic and microscopic scale to compute a feasible, stable and robust timetable. While our approach makes the trade-off between supplements and buffer times on the microscopic scale, in their approach this trade-off is made during the macroscopic

timetabling phase and they only evaluate it afterwards on the microscopic scale. The authors of [5] construct a timetable and make a platform assignment for the whole Belgian railway network. However, also here, the decision on the inclusion and the amount of supplements is made on the macroscopic level and only slightly adapted in case of infeasibilities on the microscopic level.

We set up an approach in which a routing model, a timetabling model and a simulation tool interact. The routing model constructs a routing that minimizes the capacity usage of the railway station area for a given line planning [2]. The routing model is extended to take capacity usage in terms of time into account in order to do an early check for infeasibilities. Subsequently, a timetabling model strives to maximize the buffer times between the trains, while constructing a conflict-free and realizable timetable. We extended the timetabling model proposed in [2] to take passenger numbers into account. Based on the output of the simulation tool of [3], we determine where, how large and for which trains it is useful to include supplements in the running and dwell times. This information is used as feedback for the routing and timetabling model to construct a better routing plan and timetable.

The main contribution of this work is an approach to construct a conflict-free and passenger robust routing plan and timetable for a large and complex railway station area in which the amount and placing of buffer times and supplements is carefully optimized. The approach is validated on Brussels' complex railway station area by using data from the Belgian railway infrastructure manager Infrabel. The passenger robustness can be improved with up to 17.6% compared to a reference timetable from Infrabel and up to 5.8% compared to a reference timetable from literature [2].

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A Benders decomposition approach for locating stations in a one-way electric car sharing system

Hatice Çalık
Université Libre de Bruxelles, Department of Computer Science
e-mail : hatice.calik@ulb.ac.be

Bernard Fortz
Université Libre de Bruxelles, Department of Computer Science
e-mail : bernard.fortz@ulb.ac.be

Car sharing systems are based on shared use of vehicles owned by a company or organization and they attract attention in cities with traffic congestion and high parking costs.

Our focus is on a one-way station-based electric car sharing system where we have a fleet of identical electric cars with battery restriction. The users of the system are required to visit recharging stations to pick up and leave cars but they are allowed to leave cars to a station different than the one they are taken. We need to decide on the number and location of the stations to locate as well as the number of cars available at each station before we get the complete information on demand. We represent uncertainty in demand by introducing multiple scenarios. The objective is to maximize the expected profit of the company which takes into account the expected revenue obtained from user requests that can be served and the total cost of opening stations and purchasing or leasing the cars.

We develop a Benders decomposition algorithm based on a path based mathematical formulation that we propose. We enhance the convergence speed of our algorithm with a stabilization method and valid inequalities.

Acknowledgement : This research is conducted under e4-share (Models for Ecological, Economical, Efficient, Electric Car-Sharing) project funded by FFG, INNOVIRIS and MIUR via JPI Urban Europe.

A ruin & recreate heuristic for capacitated vehicle routing problems

J. Christiaens and G. Vanden Berghe
KU Leuven, Department of Computer Science, CODeS & imec-ITEC
e-mail: jan.christiaens@cs.kuleuven.be

The capacitated vehicle routing problem (CVRP) represents a special case of the real-world vehicle routing problem (VRP). The CVRP considers a depot, a set of customers and an unlimited number of identical vehicles, each of which has a limited capacity. Customer demands are expressed in terms of a required quantity of unspecified freight. Travel times and/or distances between each pair of locations are provided. The CVRP's objective is to satisfy all customer demands by designing routes departing from and ending at the depot, while minimizing the total travel time or distance across all vehicles. Each customer must be visited exactly once and a vehicle's capacity must not be exceeded during its entire route.

Despite its simplification when compared against general vehicle routing problems, CVRP instances remain difficult-to-solve combinatorial optimisation problems. A recent CVRP benchmark set introduced by Uchoa et al. [1] includes instances containing up to 1000 customers. Most of these instances have been heuristically solved, thereby encouraging further research with regard to faster and more powerful heuristics. The availability of numerous local search heuristics for the VRP complicates the development of a heuristic approach to the CVRP since general guidelines concerning their selection and application are currently lacking.

The present research introduces a single general ruin & recreate heuristic entitled ASB-RR (Adjacent String removal & greedy insertion with Blinks - Ruin & Recreate) to replace previous heuristics. This new heuristic, incorporated in a simulated annealing framework, is capable of improving a substantial number of the CVRP instances in a small amount of time. The authors will discuss ASB-RR in three primary contexts: (i) comparing and contrasting it against existing VRP heuristics, (ii) presenting its implementation details, and (iii) analyzing its performance on CVRP instances. Full computational results are available in [2].

Acknowledgments

Work funded by IWT 130855 grant of Flanders Innovation & Entrepreneurship (VLAIO) in cooperation with Conundra (www.conundra.eu), and supported by the Belgian Science Policy Office (BELSPO) in the Interuniversity Attraction Pole COMEX (http://comex.ulb.ac.be). Editorial consultation provided by Luke Connolly (KU Leuven).

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A statistical methodology for analysing heuristic algorithms

J. Corstjens, A. Caris, B. Depaire
Hasselt University, Research Group Logistics
e-mail: jeroen.corstjens@uhasselt.be

K Sörensen
Antwerp University

Heuristic experimentation commonly entails running an algorithm on the instances of some standard benchmark problem set and measuring its performance — solution quality, run time or both. These performance results are then compared with the results other heuristic algorithms obtained on this benchmark problem set. It is a type of evaluation that ensues a competition with state-of-the-art methods in the literature. The goal is to obtain a better solution quality and/or a faster running time on the benchmark instances than other existing algorithm and claim first place in the "horse race". This approach, however, does not seek to explain why one method performs better than another one [2]. Which elements of the heuristic algorithm have contriubted to a greater or less extent to this superior performance? Is it mainly due to a certain (combination of) operator(s) employed within the algorithm? Or fixing certain parameters at specific values? Or maybe it is due to a researcher's superior coding skills leading to a more efficient implementation of an existing algorithm? Do all components significantly contribute to the performance of the algorithm, or can certain elements be left out, thereby possibly increasing the efficiency of the method? These are all questions that often remain unanswered when a new method is presented. Even though some competition between researchers might spur innovation, it has been noted that true innovation builds on the understanding of how a heuristic algorithm behaves, and not on proof of competitiveness [5]. A competitive focus works when considering a specific setting [4], but when the objective is to learn how the different heuristic elements contribute to performance and make statements beyond a specific problem setting, a statistical evaluation methodology has to be applied.

We propose a statistical methodology with the principal aim of gaining a thorough understanding of the relationship between algorithm performance, algorithmic properties, and problem instance characteristics. We wish to identify how the algorithmic properties impact algorithm performance, positively or negatively, and how these effects vary across different parts of the problem space. The proposed methodology relies on multilevel models that enables to study how algorithmic parameter effects vary given different problem conditions.

In a first application of the methodology a number of randomly generated instances for the vehicle routing problem with time windows are solved using a simplified version of the Adaptive Large Neighbourhood Search algorithm [3]

that considered less operators and also removed the adaptive mechanism used to assign weights to the operators after each iteration. The results showed that including more operators to an algorithm does not necessarily lead to a better performance in terms of solution quality. We often observed better results for configurations with only one repair operator and one or two destroy operators. Furthermore, the characteristics of a specific instance influence these effects in such a way that conclusions differ, for example, between instances with a small number of instances and instances with many customers [1]. For a second experiment, we include the adaptive mechanism for assigning weights to the operators per iteration, compare the findings with our first experiment and seek to expose the contribution of the adaptive process.

Acknowledgements

This work is supported by the National Bank of Belgium and the Interuniversity Attraction Poles Programme initiated by the Belgian Science Policy Office (research project COMEX, Combinatorial Optimization: Metaheuristics & Exact Methods
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What types are there? Assigning individuals to preference types.

Sam Cosaert
Luxembourg Institute of Socio-Economic Research (LISER) and
Department of Economics, University of Leuven (KU Leuven).
Porte des Sciences 11, L-4366 Esch-sur-Alzette, Luxembourg.
E-mail: sam.cosaert@liser.lu

1 Introduction

In many datasets on consumption and labour supply, individuals are observed only once. The estimation of demand functions and labour supply functions then requires the pooling of individuals. Although these estimation techniques take variation in observed characteristics into account, the variation in demand and labour supply outcomes cannot be fully captured by observed characteristics. This is also reflected in the typically low R^2 : only a small fraction of the variation in outcomes is captured by variation in observed characteristics. Instead of pooling all individuals and adding error terms to the demand or labour supply functions, the current study follows a different approach. More specifically, this study partitions a dataset from the Longitudinal Internet Studies for the Social Sciences in the minimum number of sets so that the utility maximisation hypothesis holds simultaneously for all individuals within a set. +

2 Contributions

First, the idea of describing choice by multiple rationales (by Kalai et al. (2012)) is brought into practice, to compute the minimum number of utility functions necessary to rationalise consumption and labour supply choices in the cross–section. Complementary to Crawford and Pendakur (2013), who used approximation algorithms to compute the minimum number of partitions necessary to break violations of the Generalised Axiom of Revealed Preference (GARP), the current study uses insights from graph theory to efficiently compute the partitions necessary to break violations of the Weak Axiom of Revealed Preference (WARP). This follows a suggestion by Apesteguia and Ballester (2010), who argued that the problem of computing the minimum number of rationales is very complex, and that insights from graph theory may be helpful to address the problem. In a first step, a graph is constructed in which vertices represent individuals and edges represent pairwise violations of WARP. In a second step, it is shown that the minimum number of partitions necessary to break all WARP violations is

equivalent to the chromatic number applied to this graph. The chromatic number always bounds the minimum number of utility functions in the sample from below. Furthermore, a wide range of algorithms from the computer science and operations research literature–to compute the chromatic number–can be applied to solve this problem, both approximately (using a greedy algorithm) and optimally.

Second, the current paper deals with the recovery of sets of individuals with homogeneous preferences (in contrast to Crawford and Pendakur (2013) who focused mainly on computing the number of sets). To this end, variation in observed characteristics is used. In particular, the nonparametric (revealed preference) conditions are complemented with an objective function that minimises observed dissimilarities within each preference type. On the one hand, this objective function provides the additional structure that is necessary to select one particular partitioning of the sample. On the other hand, this novel revealed–preference–consistent clustering builds the bridge between cluster analysis and revealed preference theory (in casu: WARP). Indeed, dissimilarities in observed demographic variables within clusters are also minimised, but in a theoretically robust way. This contrasts with the traditional clustering approach, in which clusters need not be consistent with the utility maximisation hypothesis.

3 Application

The methods are applied to consumption and labour supply choices by Dutch households (LISS). The cross–sectional variation in wages provides strong empirical bite. It turns out that there are four types of men and three types of women in the sample, which lies between the lower and upper bounds (one and four) generated by Crawford and Pendakur (2013)'s algorithm. Subsequently, this project focuses on the recovery of reservation wages–associated with full time work–per preference type. Towards this end, individuals are assigned to (three or four) preference types in a way that maintains consistency with the revealed preference axioms and minimises the difference in observables (in casu age). The results indicate considerable variation in the reservation wages across types.

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Identification of collaborative shipping opportunities using BBaRT

S. Creemers
IESEG School of Management,
KU Leuven,
e-mail: s.creemers@ieseg.fr

J. Beliën
KU Leuven,
e-mail: jeroen.belien@kuleuven.be

G. Woumans
IESEG School of Management,
KU Leuven,
e-mail: woumansgert@telenet.be

R. Boute
Vlerick Business School,
KU Leuven,
e-mail: robert.boute@kuleuven.be

A growing trend in improving logistics efficiency is to set up logistics partnerships with other companies. One can distinguish between *vertical* and *horizontal* supply chain collaborations. Vertical collaborations are established between suppliers and buyers. An example of vertical collaboration is sharing information on customer orders upstream the supply chain in order to reduce demand uncertainty for the suppliers. Horizontal collaborations are established between companies that operate at the same level in different supply chains, i.e., between suppliers or between buyers. Sharing transportation capacity when moving freight is an example of horizontal collaboration, an option that benefits the environment and yields substantial network efficiencies. It is even possible that two "co-opetitors" set up a horizontal cooperation (Leitner et al., 2011). Horizontal partnerships in logistics have the potential to generate substantial gains by leveraging the overlaps in transport networks (Leitner et al., 2011). Whereas vertical collaborations have already been successfully established for many years, horizontal collaboration initiatives are more recent and are expected to become more widespread in the near future.

The bundling of freight is nothing new, since this is essentially what logistics providers do. When companies outsource their logistics to a logistics service provider, the provider can combine freight loads of their customer base if shipment timings are identical and if there is a geographical match. Collaborative shipping is different: opportunities are detected prior to shipment, and if desired, plans are changed and shipments are delayed or moved forward in order to benefit from joint transport. The consolidation is both in geography and in time, i.e., a shipment might be rescheduled if it creates synergies. More flexibility of each partner allows to exploit more opportunities for bundling, and allows to create better and cheaper distribution plans (Vanovermeire and Sörensen, 2014). Boute et al. (2011) report on the collaboration of two pharmaceutical companies, Baxter and UCB, where synergies are generated by flexible planning: Baxter has the possibility to postpone some of its orders, which frees up space for UCB who was shipping low volumes with a lower frequency. This contrasts with tra-

ditional freight groupage, which is mainly reactive: in groupage shipping, the logistics provider decides upon bundling LTL (less than container loads) in the execution phase, rather than in the planning phase, and the consolidation is only geographical, i.e., the timing of the shipments is not allowed to change.

Until today, the potential of horizontal supply chain collaboration remains largely untapped. Establishing horizontal partnerships is also not straightforward. Even when companies are willing to cooperate, there are still many practical impediments. A survey by Cruijssen et al. (2007) shows that finding suitable partners is seen as the third largest impediment (after the allocation of the gains and the identification of partners that are able to coordinate the activities). Suitability depends on both tangible (e.g., companies with similar transport lanes) and non-tangible aspects (e.g., trust between companies). We focus on the tangible aspects and evaluate the geographical compatibility of a partnership. Potential partners need to have transport routes that are at a close enough distance so that trucks/empty space can be shared. Our tool allows to identify all relevant collaborative shipping opportunities for a given company: (1) bundling transports that have roughly the same origin and destination, (2) using an empty back-hauling trip for another transport, or (3) avoiding empty back-hauling trips by making a round trip that consists of three or more stops. In addition, our tool also detects collect-and/or-drop opportunities where shipments are collected and/or dropped off en route. We refer to our tool as "BBaRT": Bundling, Backhauling, and Round-trip Tool. BBaRT has among others been implemented by the company Tri-Vizor.

Tri-Vizor is a facilitator and orchestrator of logistics horizontal collaboration partnerships. It identifies potential collaborative shipping partnerships and is in charge of the operational coordination and synchronization of the shipments. To do so, Tri-Vizor relies on the geographical shipping data of these companies to analyze their compatibility. Over time, their database has become very large and thus very time consuming to analyze on a manual basis. BBaRT helps to automate the process and allows to quickly detect promising partnerships that are compatible with respect to cargo and routing.

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Tuning irace using surrogate tuning benchmarks

Nguyen Dang
KU Leuven KULAK, CODeS, imec-ITEC, Belgium
e-mail : nguyenthithanh.dang@kuleuven.be

Leslie Pérez Cáceres
IRIDIA, CoDE, Université libre de Bruxelles, Belgium
e-mail : lperez@iridia.ulb.ac.be

Thomas Stützle
IRIDIA, CoDE, Université libre de Bruxelles, Belgium
e-mail : stuetzle@ulb.ac.be

Patrick De Causmaecker
KU Leuven KULAK, CODeS, imec-ITEC, Belgium
e-mail : patrick.decausmaecker@kuleuven.be

The problem of algorithm parameter tuning/configuration is defined as follows : given an algorithm with a number of parameters, which can be categorical, ordinal, integer, continuous or a mix of those types, a problem instance set normally drawn from a distribution, a cost metric for evaluating the performance of each algorithm configuration on a problem instance, e.g., solution quality obtained after a limited amount of running time, and a performance measure to aggregate the cost metric values of each algorithm configuration on the whole problem instance set, we need to find algorithm configurations that optimize the performance measure. *irace* is a tool that supports doing this task automatically. However, *irace* also has its own parameters. Users could either choose to use the default values recommended by *irace*'s developers, or set those parameters according to their own tuning/configuration scenario. The latter option might not be straightforward, since the questions of how those parameters influence *irace*'s tuning performance, and whether the current default values have been the best choice or not are not trivial. Studying those questions on real tuning scenarios is impossible due to the expensive computational resource required. In this work, we tackle this problem using surrogate tuning benchmarks : for each tuning scenario, a regression model is built to predict the performance of each algorithm configuration on each problem instance, and this model is later on used to do a meta-tuning, i.e., tuning *irace* using an automated parameter configurator such as *irace* itself. The cheap evaluations using the surrogate benchmarks makes such a meta-tuning computationally feasible. Preliminary experimental results show that the current default configuration of *irace* can be statistically significantly improved.

Acknowledgement

This work is funded by COMEX (Project P7/36), a BELSPO/IAP Programme. The computational resources and services used in this work were provided by the VSC (Flemish Supercomputer Center), funded by the Research Foundation - Flanders (FWO) and the Flemish Government - department EWI.

The proactive and reactive resource-constrained project scheduling problem: The crucial role of buffer-based reactions

M. Davari E. Demeulemeester
KU Leuven Research group for operations management
e-mail: morteza.davari@kuleuven.be

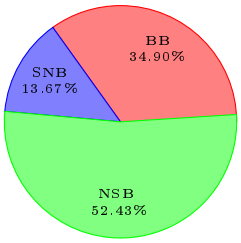
In our previous work [1], we formulated an integrated proactive and reactive scheduling problem with a combined cost function which includes a baseline schedule cost as well as costs of a series of reactions. Solutions to this problem are PR-policies. A PR-policy is described by a set of decision rules that dictate certain transitions among schedules. In our current work, we aim at understanding the importance of certain classes of reactions (*i.e.*, the class of selection-based reactions and its subclass, the class of buffer-based reactions) in constructing an optimal PR-policy.

We are given a set $N = \{0, 1, ..., n+1\}$ of activities where activities 0 and $n+1$ are the dummy start and dummy end activities. Each activity $i \in N' = N \backslash \{0, n+1\}$ has a stochastic non-negative integer duration $\tilde{p}_i$, with $p_i^{\min} \leq \tilde{p}_i \leq p_i^{\max}$, which follows a discrete distribution $dist(\tilde{p}_i)$. We assume that these stochastic durations are independently distributed. The vector $\tilde{\mathbf{p}} = (\tilde{p}_0, \tilde{p}_1, ..., \tilde{p}_{n+1})$ can be represented by a finite supporting set $\mathfrak{P} = \{\mathbf{p}^1, ..., \mathbf{p}^{|\mathbf{p}|}\}$ of realizations where each realization $\mathbf{p}^l$ represents a vector of durations $\mathbf{p}^l = (p_0^l, p_1^l, ..., p_{n+1}^l) \in \mathfrak{P}$. Notice that the durations of the dummy activities are not stochastic ($\tilde{p}_0 = \tilde{p}_{n+1} = 0$). We are also given a set $\mathcal{R}$ of renewable resource types. Each job i requires r_{ik} units of resource type $k \in \mathcal{R}$ during its processing time and the resource availability of resource type k is denoted by R_k. The set $E \in \{(i,j) | i, j \in N\}$ defines precedence constraints among the activities where the pair $(i,j) \in E$ indicates that activity j cannot be started before activity i is completed.

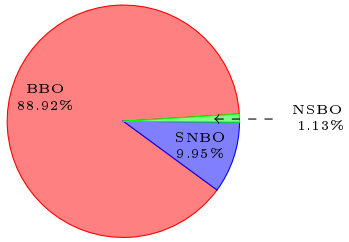
A set FS of activities is a *forbidden set* if $E \cap (FS \times FS) = \emptyset$ and $\exists k \in \mathcal{R} : \sum_{i \in FS} r_{ik} > R_k$. A forbidden set FS is *minimal* if for every $i \in FS$, the set $FS \setminus \{i\}$ is not a forbidden set. We define $\mathscr{F}(\cdot)$ as the set of all minimal forbidden sets with $\cdot$ being a partial order among activities. One may use extra resource arcs to eliminate all minimal forbidden sets. Let us define selection $X \subset N \times N \setminus T(E)$ as a set of pairs where each pair represents a resource arc. We assume that X is a strict partial order on N (*i.e.* irreflexible and transitive).

Definition 1 (Sufficient selection) *A selection X is called sufficient if and only if $G(N, E \cup X)$ is acyclic and $\mathscr{F}(E \cup X) = \emptyset$.*

Definition 2 (Selection-based reaction) *A reaction from schedule $\mathbf{s}$ to schedule $\mathbf{s}'$ is selection-based if there is a sufficient selection X that is feasible for both $\mathbf{s}$ and $\mathbf{s}'$.*



a The average contributions of different classes of reaction in the whole network



b The average contributions of different classes of reaction in the optimal PR-policy

Figure 1: The average contributions of different classes of reaction for the setting where $w_b = 25$ and $w_r = 0$

Let $ES(X, \mathbf{p})$ denote the induced early-start schedule for every given pair $(X, \mathbf{p})$. A 3-tuple $(X, \mathbf{p}, \mathbf{p}')$ induces a pair of schedules $(\mathbf{s}, \mathbf{s}')$ if X is sufficient, $\mathbf{s} = ES(X, \mathbf{p})$ and $\mathbf{s}' = ES(X, \mathbf{p}')$.

Definition 3 (Buffer-based reaction) *A reaction from* $\mathbf{s}$ *to* $\mathbf{s}'$ *is a buffer-based reaction if there exists a 3-tuple* $(X, \mathbf{b}, \mathbf{b}')$ *that induces* $(\mathbf{s}, \mathbf{s}')$.

To understand the importance of the buffer-based reactions, we depict in Figure 1 the contributions of three mutually exclusive and collectively exhaustive classes of reactions in the network and in its associated optimal PR-policy. The classes under comparison are the class of non-selection based (NSB) reactions, the class of buffer-based (BB) reactions and the class of selection-but-not-buffer-based (SNB) reactions. Figure 1a shows the contributions of these classes of reactions in the whole network and Figure 1b displays the contributions of these classes of reactions in the associated optimal PR-policy. The futility of non-selection-based reactions in the optimal PR-policy is very clear in Figure 1 (NSBO represents the percentage of non-buffer-based reactions in the optimal PR-policy): although 52.43 percent of reactions are non-selection-based, the contribution of these reactions in the optimal PR-policy is only 1.13 percent. It is also clear that buffer-based reactions are very important: as stated before, despite the fact that only 34.90 percent of reactions are buffer-based, their contribution in the optimal PR-policy is very high (88.92 percent).

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Bidding on day-ahead markets: a dynamic programming approach

J. De Boeck
Université Libre de Bruxelles, Département d'informatique
e-mail: jdeboeck@ulb.ac.be

M. Labbé
Université Libre de Bruxelles, Département d'informatique
e-mail: mlabbe@ulb.ac.be

É. Marcotte
ENGIE
e-mail: etienne.marcotte@engie.com

P. Marcotte
Université de Montréal, DIRO
e-mail: marcotte@iro.umontreal.ca

G. Savard
École Polytechnique de Montréal, Département de mathématique et génie industriel
e-mail: gilles.savard@polymtl.ca

Several markets, such as electricity's, base the price-allocation process upon a bidding process that involves producers and operators. Precisely, price-quantity bids (λ_i, g_i) of a resource are placed on the day-ahead market for each production unit i. Based on this information, a system operator minimizes the cost of meeting demand at minimal price. The spot price charged to customers is then set to the marginal price of the system operator's assignment problem.

In this context, we consider a company that optimizes its bid, taking into account those of its competitors, as well as the spot price set by the system operator. Given the uncertainty related to the bids of the competition, the problem faced by the optimizing company can be cast in the framework of stochastic bilevel programming, which has been adopted by [1, 2] in the case where the quantity part of the bids is fixed. With respect to electricity markets involving renewable energy, where the stochastic factor becomes highly relevant [3], it becomes important to develop algorithms able to integrate a large number of scenarios that make use of the latest data, e.g., accurate weather forecast.

The aim of our work is to propose an efficient dynamic programming algorithm for addressing both the original problem, as well as extensions involving variable (linear) production costs and variable (stepwise) demand function. As an alternative to the standard reformulation of the bilevel program as a computationally challenging MILP (Mixed Integer Linear Program), we propose to solve two related problems. The first one, BP-R, relaxes the assignment constraints in BP, allowing distinct bids to quantities issued from a given unit. Its solution, which can be obtained by dynamic programming in pseudo-polynomial time,

provides an upper bound on the optimal value of the original problem. Problem BP-Q is identical to BP except that quantity bids g_i are fixed in advance. The algorithm proposed for BP-R can then be adapted to solve BP-Q, and provides feasible solutions to BP. Through a combination of BP-R and BP-Q, one can construct feasible and near-optimal solutions to BP, much faster than through the solution of the single-level MILP formulation. This will be illustrated on a set of instances used in [2], whose data is issued from the Brazilian Electric System National Operator (2008).

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Automatized cargo bundling for SMEs

Dr. Philippe De Bruecker
Odisee University College - Brussels
KU Leuven - Brussels,
e-mail : philippe.debruecker@odisee.be

Prof. Dr. Wouter Verheyen
Odisee University College - Brussels
KU Leuven - Brussels
Erasmus University - Rotterdam
e-mail : wouter.verheyen@odisee.be

Full Container Load (FCL) shipping allows for cost savings compared to Less than Container Load (LCL) shipping. However, many small to medium-sized companies (SMEs) lack sufficient volume (on specific routes) to allow for FCL shipping. Hence, efficiency gains can be obtained through cooperation between different LCL shippers (cargo bundling). Such cooperation has been researched extensively in logistic research. However, the problem with such cooperation is that the cooperation itself causes significant transaction costs. These costs can, especially for SMEs, strongly reduce or even eliminate the efficiency gains generated by FCL shipping.

We believe that the solution for this problem lies in the automation of the bundling process using an online matching tool. However, the design of such an automatized cargo bundling tool creates several technical and legal problems. First, we focus on the technical aspects of such a bundling tool and present our matching algorithm and optimization procedures. We also show how a graphical web interface can be employed to make the tool usable for SMEs.

Second, beside the technical challenges, two important legal problems should be resolved by the design of the tool. A first problem lies in the matching process of the partners. If partners need to approve the collaboration with all the other partners, the transaction costs increase. Moreover, this approval procedure will also make the tool more static. A possible solution is to allow the individual companies to authorize the tool to conclude the partnerships without an explicit approval of each partner. However, this means that a potential liability exposure arises for the tool. A second problem concerns the liability consequences of the bundling. In order for cargo bundling to be a viable alternative for LCL shipping, there shouldn't be an adverse effect on the cargo interests' liability position under the carriage contract. Insofar as such effect is unavoidable, the framework agreement between the partners should therefore provide for contractual recourse mechanisms.

In our presentation we will present a combination of both the technical and legal issues in order to obtain a useful and applicable cargo bundling tool for SMEs.

The integration of individual partner objectives in the logistic optimisation model for a horizontal cooperation

C. Defryn
University of Antwerp, engineering management department
e-mail: christof.defryn@uantwerpen.be

K. Sörensen
University of Antwerp, engineering management department
e-mail: kenneth.sorensen@uantwerpen.be

Horizontal logistic cooperation is defined as a long-term agreement between companies with similar of complementary transportation needs that aim to exploit synergies by means of active bundling and synchronisation. The current research on horizontal logistic cooperation is focused mainly on assessing the costs and benefits, and the allocation of these benefits among the individual collaborating partners. To estimate the potential benefits that come with horizontal logistic cooperation, researchers make use of simulation studies that are based on either theoretical instances, or on real life case studies. For the allocation of the coalition cost or benefits, multiple allocation mechanisms have been described in the literature, ranging from cooperative game theoretical approaches to simpler rules of thumb.

Only a limited number of papers address operational planning problems in horizontal logistic cooperation. Also, when quantifying the cost saving of such logistic collaborations, existing models do not take into account to which partner a transportation request originally belonged. It is even not acknowledged that all transportation requests actually belong to multiple companies. Therefore, no distinction is made between the objective of the coalition of collaborating companies and the objective of each individual company. Although the coalition as a whole should perform as efficient as possible to exploit the synergies from the collaboration, all collaborating partners remain independent entities that tend to favour a solution that is best according to their own objectives. In Defryn and Sörensen (2016), we are the first to argue that the objectives of both levels should be taken into account.

We propose a general framework that aims at integrating both objective levels of horizontal logistic cooperation for an n partner coalition. The main motivation for the group to invest in this long-term relationship is given by a common goal on which all partners agree, i.e., the *coalition objective*, as expressed in the following, generalised, optimisation model,

$$F_c(x^*) = \min\left(F_c(x)\right)$$
$$\text{Subject to}$$
$$x \in \zeta$$

in which $F_c(x)$ is defined as the *coalition objective* and a solution vector $x \in \zeta$ is to be determined such that the coalition objective is minimised. The definition of the solution space ζ will depend on the logistic problem studied. Let x^* be the optimal solution vector and $F_c(x^*)$ the corresponding value of the objective function.

Now, each collaborating company is given the opportunity to express which characteristics of the solution x it deems important. This gives rise to another set of objective functions, i.e., the *partner objectives*. These objectives, denoted as $F_i(x)$, with $i = \{1, \ldots, k\}$, should assure that all partners evaluate the proposed solutions as beneficial and therefore do not have the intention to leave the coalition. Each partner is free to impose either none, a single, or multiple additional objectives to the optimisation procedure.

Let $d(a, b)$ be a distance measure between two solutions $a, b \in \zeta$, and let ϵ, be a parameter that states the acceptable deviation from the optimal coalition solution x^*. Now, define the neighbourhood of x^* as follows:

$$N(x^*) = \{x | d(F_c(x), F_c(x^*)) \leq \epsilon\}$$

This neighbourhood comprises all solution vectors $x \in \zeta$ that are within a distance ϵ from x^* with respect to the coalition objective value. We can now define the multi-objective optimisation problem that includes all partner objectives as follows:

$$\min_{x \in \zeta}\left(F_1(x), \ldots, F_k(x)\right)$$
$$\text{Subject to}$$
$$x \in N(x^*)$$

The result of this multi-objective optimisation model is a Pareto set of non-dominated solutions with respect to the individual partner objectives. Furthermore, we assure that all reported solutions remain close to the optimal solution at the coalition level. In this way, the size of the solution space is reduced by focusing only on the most promising solutions that ensure a certain level of efficiency for the coalition as a whole. This approach also allows to control the size of the solution set provided to the decision maker by varying the size of the neighbourhood.

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Adding a Sequence Variable to the OscaR.CBLS Engine

Renaud De Landtsheer Yoann Guyot
Gustavo Ospina Christophe Ponsard
CETIC Research Center, {rdl,yg,go,cp}@cetic.be

Constraint-Based Local Search (CBLS) is an approach for quickly building local search solvers based on a declarative modelling framework for specifying input variables, constraints and objective function. An underlying engine can efficiently update the optimization model to reflect any change to the input variables, enabling fast exploration of neighbourhoods as performed by local search procedures.

This approach may suffer from a major weakness when moves involve modifying the value of a large set of input variables in a structured fashion. For instance, in routing optimization, if one implements the optimization model by means of an array of integer variables, a two-opt is implemented by modifying the value of each variable involved in the flipped segment. Global constraints are then unable to exploit the structure of the move to evaluate neighbours efficiently.

To mitigate this *multi-variable limitation* in the context of vehicle routing and other sequence-based optimization problem, we propose an efficient implementation of a variable type for CBLS engines that represents sequences of integers. The proposed implementation offers good complexities for updating and querying the value of sequences of integers and also incorporates a mechanism that allows global constraints to perform pre-computations, so that they can rely on efficient algorithms to evaluate neighbour solutions quickly.

1 Features of our Sequence variable

Our implementation distinguishes sequence variable and sequence value. A sequence variable is assigned a sequence value. A sequence value is immutable and represents a sequence of integers as a continuous mapping from positions to integers, where positions range from zero to the size of the sequence minus one.

Our dedicated data structure supports three updates: insert an integer value or delete the value at a given position, and move a subsequence. Such *seq-move* is parametrized by the start and end position of the moved subsequence, the position where the moved subsequence is to be moved and a Boolean specified if the moved subsequence is flipped during the move.

Our implementation of sequence variable and its underlying data structure for representing sequence supports:

1. the very fast update of sequence variable in the context of neighbourhood exploration, and the efficient query/exploration of sequence values

2. the symbolic description of incremental moves (insert, delete, seq-move, and any composition of them). Invariants that derive values from sequences are notified about such symbolic update.

3. a checkpointing mechanism that enables invariant to perform pre-computation at the start of each neighbourhood exploration. Some invariant can be implemented in a very efficient way if such pre-computation is possible.

4. the fast update of sequence variable when a move is committed.

2 Underlying Data Structure

The underlying data structure for representing a sequence of integer features two main parts. First a concrete sequence is represents sequence, typically at the start of neighbourhood exploration. Second, a set of updated sequences has been implemented, to represent a sequence after a move (seq-move, insert, remove) has been applied to it. Such updated sequences are used for neighbourhood exploration, can be instantiated in $O(1)$, and introduce a $O(1)$ overhead over most queries that are supported by our sequences.

The concrete representation of a sequence represents the map from positions to values through a double mapping that maps positions to an internal position and then maps the internal position to the actual value. The first mapping is a piecewise affine bijection, where each affine piece has a slope $+1$ or -1 and an offset. The second mapping is made of two red black trees, one maps the internal position to the actual value, and the other is the reverse. The goal of this double mapping is that the first mapping can be efficiently updated to reflect a seq-move.

3 Conclusion

This new variable type will be included in the CBLS engine of OscaR 4.0 to be released in Spring 2017, together with a set of adapted and efficient global constraints, notably for routing optimization (routing cost matrix, node-vehicle restrictions, etc.) [1]. We hope that OscaR.cbls will be even more appealing both to users that benefit from highly efficient global constraints in a declarative local search engine, and to researchers who aim at developing new algorithms for global constraints on sequences [2] and benefit from the whole environment of OscaR.cbls so they can focus on their own contribution.

Acknowledgement This research was conducted under the SAMOBI CWALITY research project from the Walloon Region of Belgium (grant nr. 1610019).

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Planning doctor shifts in hospitals: an approach focusing on perceived fairness

Gaetan Delannay, Renaud De Landtsheer, Christophe Ponsard
CETIC Research Centre, Charleroi, Belgium MedErgo, Belgium
gaetan.delannay@geezteem.com, {rdl,cp}@cetic.be

Producing planning of physician's roles, including on duty, on call, and regular working day in a hospital is a complex task. Furthermore, such a solution require a very good user acceptance to be effectively deployed in production. This paper reports on the application of metaheuristics to solve this problem and focuses on user acceptance aspects of the selected planning algorithm. The proposed solution is actually being deployed by MedErgo, a Belgian company, under the form of a web-based application for hospital physicians planning, called *Nice Watch* [1].

1 Context

Guard-scheduling problem is to determine the rotating shifts of the staff over a schedule period. This classical problem is known to be NP-Hard. Recent work is increasingly taking into consideration the staff's preferences in planning the schedule of shifts and days-off and adopt maximization of satisfaction to evaluate the quality of produced solution [2].

Automatic preparation of guard schedules requires to take into account complex constraints like part-time, absences, recoveries, work over holidays and week-ends, etc. To maximise user acceptance, the solution should also allow the doctors to express preferences, to barter duty roles and provide evidence of fairness.

2 Frustration in planning composition

There are well established rules related to planning compositions. One of them is related to compensation. For instance, when a doctor has an on site duty during the week-end, he gets half a day off that can be placed freely. When a doctor has a night duty on a Thursday, he gets Friday off. Thursday duties are therefore much more attractive than Saturday duties. Planning composition should therefore be fair among doctors about this attractiveness of duties. Inside a large doctor's team, it's indeed impossible to set up a monthly planning that takes into account all the loads or attractiveness of this peculiar month. One must thus figure out a way to spread out the workload among individuals and over longer time frames.

Besides, there are elements of knowledge or habits that are not communicated and can cause frustrations directed towards the crew that composed the planning. When relying on an uninformed automated tool, untold constraints can obviously not be taken into account and this avoid the emergence of frustration.

3 User acceptance through understandability

Planning algorithms can always be biased in one way or another by the person in charge of the planning, and well-established generic algorithms such as CP, LNS, or MIP can be perceived by the user as an efficient, but obscure black box that might raises suspicions regarding the fairness of the tool.

One of the key aspect of the approach developed with MerdErgo is to ensure user acceptance was to ensure the understandability of the delivered solution. This includes the understandability of both the algorithm itself and its executions. However, human nature being what it is, there will always be people convinced that the algorithm was precisely designed to ensure them a heavier workload.

The algorithm is a composition of local search, greedy algorithms, tabu search, and a few additional metaheuristic principles, and proved both good enough and fast enough for real hospital-life.

A notable fact is that the delivered algorithm is probably not optimal with respect to fairness, since it does not guarantee optimality, but it is probably optimal with respect to the perceived fairness, which is more important for user acceptance. Of course, improvements to the algorithm can be considered and it might be later replaced by more efficient, and more optimal solutions, once such solution is well-established. It is thus to consider as a first iteration over a long-lasting change process. One must also consider that even a sub optimal algorithm is, by far, much more fair and reliable than the best skilled human planner. This greatly improves the fast team acceptance of a mathematical-driven approach to planning composition.

A very sensitive point for physicians working in intrahospital teams is that the workload regarding night duties, week-end shifts and other unattractive chores must be as evenly as possible spread among individuals, but according to team-specific rules : seniority being the most thoroughly in use. Individual statistics with personal data counting up the annual numbers of night and week-end shifts works best to insure everyone he took his part, but not more, in the mandatory workload. More than a deep understanding of the algorithmic process and its fairness, those raw unquestionable values demonstrate for each user how fair - or not- the system was to him. The tool's ability to reach similar values for similar users is seen as the best proof of its efficiency and its fairness. Data take precedence over perception.

Our automated planning composition tool was deployed in production since August 2016 in a Belgian hospital, as part of the *NiceWatch* web-based platform for doctor management [1]. It took time but eventually the team's members admitted that the algorithm was fair to everyone at least one the long run.

Acknowledgement This work was conducted as part of the PRIMa-Q CORNET project (nr. 1610019). We warmly thanks MedErgo for sharing their case.

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A GRASP heuristic for the Discrete Ordered Median Problem: how to exploit it into an exact method

S. Deleplanque
Université Libre de Bruxelles, Département d'Informatique
e-mail: sdelepla@.ulb.ac.be

M. Labbé
Université Libre de Bruxelles, Département d'Informatique
e-mail: mlabbe@.ulb.ac.be

D. Ponce
Université Libre de Bruxelles, Département d'Informatique
Instituto de Matemáticas de la Universidad de Sevilla
e-mail: dponce@us.es

J. Puerto
Universidad de Sevilla, Departamento de Estadística e Investigación Operativa
Instituto de Matemáticas de la Universidad de Sevilla
e-mail: puerto@us.es

GRASP, Greedy Ramdomized Adaptive Search Procedures, is a well-known heuristic technique that usually exhibits good performance in short computing time ([1]). In this work we apply GRASP heuristic to the Discrete Ordered Median Problem (DOMP).

For the sake of comprehension, let us give a brief explanation of DOMP (see [2] for more information). Let C be the cost matrix, C_{ij} is the cost to serve the demand point i with facility j. We have n demand points, which at the same time are the candidate sites to be facilities. Let I be the set of demand points and let J be the set of servers, such that $J \subseteq I$, the DOMP is characterized by a set of constraints: the problem must have exactly p facilities, where $1 \leq p \leq n$ and every client must be served.

In order to define the objective function in DOMP, we need to calculate the vector c. This vector has n components, which are the sorted cost for each location, i.e. $c_i(J) = \min_{j \in J} C_{ij}$. By means of a permutation we obtain the vector $c_{\leq}$, such that it satisfies $c^1_{\leq}(J) \leq \cdots \leq c^n_{\leq}(J)$.

Then, we have to solve next problem

$$\min_J \sum_{k=1}^{n} \lambda^k c^k_{\leq}(J),$$

where λ is a n-vector with $\lambda^k \geq 0 \, \forall k$.

The two main parts of a GRASP heuristic are the construction of a solution and the improvement of this given solution. This is done by means of random and greedy procedures for the construction and by means of the use of local search for the improvement. We have developed *ad hoc* algorithms for both the greedy construction and the local search.

Our GRASP algorithm consists in a multistart greedy algorithm to construct a set of p facilities from a randomly generated set of facilities with smaller cardinality. The greedy algorithm iteratively add a new facility to the current set of open facilities, choosing the one with the maximum improvement of the objective value. The local search consists in an interchange heuristic between open and closed facilities. The pseudocode of the GRASP used to solve the problem is the following.

Algorithm 1 GRASP for DOMP.

```
1: Input();
2: for n_1 replications do
3:    PartialSolution ← ConstructRandomizedPartialSolution (q);
4:    Solution ← ConstructGreedySolution (PartialSolution);
5:    for n_2 iterations do
6:       Solution ← LocalSearch(Solution);
7:       BestSolution ← UpdateSolution (Solution, BestSolution);
8:    end for
9: end for
```

GRASP is a simple heuristic, in terms of parameters, which we need to calibrate. Here we compare the time and the quality of the solution with different alternatives. The tested parameters are the number of servers open randomly (q), the number of iterations (n_1) and the number of local search (n_2). We show the necessary CPU-time and the quality of the solution for different options.

Despite the quality of the solution one cannot ensure optimality unless the DOMP is solved by exact methods. In this work, we integrate the new heuristic in a Branch-and-Cut-and-Bound and in a Branch-and-Cut-and-Price frameworks. Once we have a feasible solution for the problem we provide it to the resolution framework. In particular, we show the benefits of using this integer solution in the Branch-and-Bound process as an upper bound. Its main benefit lies on the improvement of the number of nodes, i.e. on the reduction of the size of the Branch-and-Bound tree.

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The expected loss revenue function of a MAP/PH/1/C queue

S. Dendievel
Ghent University, Department of TELIN, SMACS Research Group
e-mail: sarah.dendievel@UGent.be

S. Hautphenne
The University of Melbourne, School of Mathematics and Statistics
e-mail: sophiemh@unimelb.edu.au

G. Latouche
Université libre de Bruxelles, Département d'informatique
e-mail: latouche@ulb.ac.be

P.G. Taylor
The University of Melbourne, School of Mathematics and Statistics
e-mail: pgt@ms.unimelb.edu.au

Abstract

In a $MAP/PH/1/C$ queueing system, customers are lost when they arrive to find C customers already present. Assuming that each arriving customer brings a certain amount of revenue, we are interested in calculating the expected amount of revenue that the queue will lose over a finite time horizon $[0, t]$, as well as exploring the limit of the rate of losing revenue in the asymptotic regime.

1 Introduction

We consider the problem of computing the expected amount of lost revenue in a $MAP/PH/1/C$ queue over a finite time horizon $[0, t]$ given its initial occupancy. We can think of this as a matrix generalisation of the similar analysis for the $M/M/C/C$ model analyzed in Chiera and Taylor [3] and the $M/M/1/C$ model in Braunsteins, Hautphenne and Taylor [2].

The Markovian arrival process (MAP) is defined by two matrices D_0 and D_1 of order n_1. The service time follows a phase-type distribution $PH(\boldsymbol{\tau}, T)$ of order n_2, with $\boldsymbol{t} = -T\mathbf{1}$. The $MAP/PH/1/C$ queue may be modelled as a finite quasi-birth-and-death process (QBD) $\{X(t)\}_{t\geq 0} = \{(J(t), \varphi(t))\}_{t\geq 0}$ with levels $0, 1, \ldots, C$ corresponding to the possible queue lengths. Here, $0 \leq J(t) \leq C$ represents the number of customers in the system at time t, and $\varphi(t) = (\varphi_1(t), \varphi_2(t))$ where $0 \leq \varphi_1(t) \leq n_1$ is the phase of the MAP at time t, and $0 \leq \varphi_2(t) \leq n_2$ is the phase of the PH distribution at time t. The generator of the QBD process

has a block-tridiagonal form given by

$$Q = \begin{bmatrix} D_0 \otimes I & D_1 \otimes I & & & \\ I \otimes \boldsymbol{t} \cdot \boldsymbol{\tau}, & D_0 \oplus T & \ddots & & \\ & \ddots & \ddots & & \\ & & & D_0 \oplus T & D_1 \otimes I \\ & & & I \otimes \boldsymbol{t} \cdot \boldsymbol{\tau}, & (D_0 + D_1) \oplus T \end{bmatrix},$$

where the block matrices are of size $n = n_1 n_2$ and where $\otimes$ and $\oplus$ denote the Kronecker product and sum, respectively.

2 The expected loss function

Let $V_{ij}(t)$ be the expected cumulative time spent in state j in the time interval $[0, t]$, given that the process starts in state i at time 0, and define the matrix $V(t) = (V_{ij}(t))$. Associate a loss g_j per time unit when $\{X(t)\}$ occupies state j, and define the vector $\boldsymbol{g} := (g_j)$. Then the expected revenue lost in $[0, t]$, given that the process starts in state i, is given by $R_i(t) := (V(t)\boldsymbol{g})_i$, so that the vector $\boldsymbol{R}(t) := (R_i)$ is equal to

$$\boldsymbol{R}(t) = (\boldsymbol{\pi}\boldsymbol{g})\mathbf{1}\, t + D(t)\, \boldsymbol{g},$$

where $\boldsymbol{\pi}$ is the stationary vector of the QBD process, $\mathbf{1}$ denotes the column vector of 1's, the transient deviation matrix is defined by

$$D(t) = \int_0^t \left(e^{Qu} - \mathbf{1}\boldsymbol{\pi}\right) du,$$

see [2]. The expected revenue loss function has a linear asymptote, $\boldsymbol{R}(t) \sim (\boldsymbol{\pi}\boldsymbol{g})\mathbf{1}\, t + D\boldsymbol{g}$, where $D = \lim_{t\to\infty} D(t)$ is the deviation matrix, see [4].

We analyse the transient behaviour of the expected loss function in the Laplace transform domain. An explicit expression for $\tilde{\boldsymbol{R}}(s) = \int_0^\infty e^{-st}\boldsymbol{R}(t)\, dt$ is given by $\tilde{\boldsymbol{R}}(s) = (sI - Q)^{-1}(1/s)\boldsymbol{g}$, but this expression does not give any insight in the structure of the blocks $\tilde{\boldsymbol{R}}_k(s)$, which are conditional on the initial queue length, nor in the role of the maximum capacity C in the solution. Instead, we rewrite $\tilde{\boldsymbol{R}}(s)$ as a system of second-order matrix difference equations and compute of the blocks $\tilde{\boldsymbol{R}}_k(s)$, for $0 \le k \le C$, by following an argument similar to the one in [1].

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Gradient-based optimization of the expected profit in a serial production line with single sampling plans

S. De Vuyst, D. Claeys, B. Raa, E.H. Aghezzaf
Ghent University, Departement of Industrial Systems Engineering and Product Design
e-mail: Stijn.DeVuyst;Dieter.Claeys;Birger.Raa;ElHoussaine.Aghezzaf@ugent.be

We consider a serial production line consisting of K stages with single-sampling inspection after each stage $k = 1, \ldots, K$. A lot of N items goes through the stages one by one until it is rejected or reaches the end of the line. Inspection after stage k is with regard to a continuous quality characteristic (QC) X_k of the item, pertaining to that stage. The QCs are normally distributed with mean μ_k and variance σ_k^2 at stage k and they are independent, both between stages and between items. That is, we assume all processes to be strictly in control. If X_k lies between fixed lower and upper specification limits the item is considered conforming, otherwise it is defective. Single sampling inspection means that n_k items are randomly selected from the lot and inspected. If the number of defective items in the sample is larger than an acceptance number d_k, the entire lot is rejected and sold. Otherwise, the lot is sent to the next production stage. Before selling or passing to the next stage however, defective items may be reworked and a quality cost per item is incurred either before or after the rework.

The mean μ_k of the QC at stage k can be controlled and if it is, the corresponding QC standard deviation follows accordingly as a given function $\sigma_k(\mu_k)$ which can be seen as a constraint of the process at stage k. We refer to this function as the deviation response of the process. The goal is to find an optimal vector of QC means $\boldsymbol{\mu} = (\mu_1, \ldots, \mu_K) \in \mathbb{R}^K$ which maximises the expected profit,

$$\boldsymbol{\mu}^* = \arg\max_{\boldsymbol{\mu}} \mathrm{E}[\mathrm{Profit}(\boldsymbol{\mu})]\,. \tag{1}$$

We propose to solve (1) using a gradient-search procedure and provide expressions for this gradient. The property of quasi-convexity for this objective function is investigated as well as the possibility of expressing (1) as a dynamic programming problem. For a number of specific scenarios, we demonstrate the performance of the search algorithm and the nature of the solutions found.

The expected profit per lot is obtained analytically, accounting for production cost, selling price, inspection cost, rework cost as well as a Taguchi quality cost. The production, inspection and rework cost of an item at stage k are all assumed to be monotone functions of that item's QC X_k, where the case of affine functions is considered in particular. The quality cost of an item is given by the well-known asymmetric Taguchi loss function $\mathcal{Q}(X_k) = (X_k - T)^2(W_0 \mathbb{1}_{X_k<T} + W_1 \mathbb{1}_{X_k \geqslant T})$, which favours the production of items with quality close to a target value T.

The optimization of the process means in a serial production line with sampling was considered before. In [1] a multi-objective optimization of a single stage is discussed while [2] studies the impact of inspection errors. In [3] the production of single items (instead of lots) is considered which may require multiple rework cycles at each stage before progressing to the next. The authors of [3] show that for their model, the optimization (1) can be done sequentially, stage by stage, and they obtain explicit expressions for the solution.

Our model is in fact a generalisation of the study in [4] which in turn was based on the two-stage model without quality cost in [5]. Unlike these previous models however, we allow the production, inspection and rework costs of an item in each stage to depend on its QC, instead of being fixed. The rework and quality cost functions may depend on whether the item belongs to the inspection sample or not and whether the lot is accepted or not. Also, the quality cost may be incurred either before or after the rework. This versatility of the model allows to cover a large array of different system variants with different policies for inspecting, reworking and assessing the quality of the lots. These policies are not necessarily the same for each production stage, although it is required that rejected lots leave the production line and do not progress to the next stage. Further, as in previous studies we consider normally distributed QCs but we abandon the assumption that their variance remains unaltered when their mean is changed.

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Vehicle Routing in practice

Reginald Dewil
Conundra, Voordries 41, Oosterzele Belgium,
e-mail: reginald.dewil@conundra.be

Simon Crevals
Conundra, Voordries 41, Oosterzele Belgium,
e-mail: simon.crevals@conundra.be

Sam Van Malderen
Conundra, Voordries 41, Oosterzele Belgium,
e-mail: sam.vanmalderen@conundra.be

The Vehicle Routing Problem (VRP) is one of the most well-studied combinatorial optimization since it was introduced in 1959 [1]. VRP instances of relevant practical size typically number from hundreds of customers to well into the thousands of customers with hundreds of available heterogeneous vehicles. Because many additional practical constraints are usually present for logistics companies, such problems are presently still solved mainly manually by experienced planners and dispatchers. It is thus unsurprising that non-negligible to considerable savings can be obtained applying OR techniques.

Academic research typically focuses on VRPs with one, two, or three additional problem aspects such as, among many others, time-windows, legal break times, multi-depot, multi-tour, multiple compartments, dynamic, pickup and delivery [2][3][4]. However, to the best of the authors' knowledge, academic research in developing algorithms combining all practical constraints simultaneously are nonexistent or at least unpublished.

This contribution aims to emphasize the importance of researching solution approaches simultaneously considering all problem aspects. Since, often, effective algorithms or heuristics tackling a two-or-three-aspect-VRP variant break or lose their effectiveness in the presence of a third or fourth problem aspect. This can occur because the additional computational requirements are too great in the previous elegant problem representation or the problem representation is simply wholly insufficient.

We present a list of the most relevant problem aspects for logistics and industrial companies. Not all companies have need of all problem aspects simultaneously. However, it is impractical to develop and maintain algorithms used in daily operations for every possible combination of problem aspects leading to the requirement of a feature toggle. This means that the mega algorithm able to tackle all problem aspects simultaneously must be designed and implemented in such a way that when a certain aspect is not required, the performance would approximate a dedicated algorithm.

Lastly, we argue for the need of realistically sized benchmark instances combining many or all problem aspects relevant for logistics companies in practice.

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Measuring and explaining school district performance. The influence of school district management and organizational practices.

K. De Witte
KU Leuven, Leuven Economics of Education Research
kristof.dewitte@kuleuven.be
Maastricht University, Top Institute for Evidence Based Education Research
k.dewitte@maastrichtuniversity.nl

F. Schiltz
KU Leuven, Leuven Economics of Education Research
fritz.schiltz@kuleuven.be

The New Public Management theories have created a growing tendency to improve governance processes in public agencies and have stressed the importance of professionalism and optimization [1]. Since its introduction in the 1980s, hospitals, nursing homes and other government-owned agencies have been transformed into more 'market-friendly' organizations. More recently, this observed trend is spreading towards education, both at the school and the school district level [2].

Topics on management and organizational practices have been extensively discussed at the school level [3, 4]. Despite the uncommon focus on school district performance, school governing bodies are argued to play a major role in the management of schools as they determine the school's mission and goals and the selection and support of the school leader [5]. Student achievement has also been linked to the degree of organizational effectiveness in a school district [6].

This paper contributes to the literature in several ways. First, we construct an innovative empirical measure of school district performance that summarizes all board functions into one composite indicator. The indicator is a relative measure that is easy to interpret and allows school districts sufficient leeway in setting their priorities. This nonparametric approach does not impose weights on different board functions when constructing a composite indicator but rather lets the data speak for itself. Hence, school boards are granted the 'benefit of the doubt' when attaching weights to these functions. In addition, it is robust for outlying and atypical observations. We apply this methodology to our survey data (N=151) obtained from school board members and principals in Flanders.

Second, we analyze the obtained aggregate measures to identify which organizational structures, board characteristics and management practices are of importance for good governance. The current literature has stressed the importance of adequate governance for students' outcomes without looking further into what explains and contributes to the concept of 'good governance'. As a

result, there is currently no (recent) quantitative research concerning *what* is effective governance at the school district level. The two extensions provide a new data-based framework to measure and explain heterogeneity in school district performance, which has been missing in the literature up to now.

Combining our district evaluations with administrative data, we are able to infer some interesting insights. School districts organized by some type of government (municipal, provincial, or central) tend to significantly underperform. However, once organizational structure and management practices are accounted for, this negative relationship disappears. Especially consolidated districts, as opposed to (incentivized) cooperating districts, and boards adhering to a participative management style tend to outperform others. School board composition also matters. Boards with more experienced members for specific functions attain significantly higher evaluations. Remarkably, the size of the district does not matter, in contrast to statements made by Sleegers et al. (1994) for the case of the Netherlands [7].

Policy implications are straightforward. A well-managed school district led by a unified and experienced board appears to outperform other districts by almost 20 percent. Irrespective of the interpretation of this absolute value, mediocre school districts can boost their organizational effectiveness significantly by accommodating their governance model to these 'best practices'. Combining our findings with those of Bloom et al. (2015) [8], student outcomes might benefit from improved school districts through stronger accountability faced by school principals.

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Adaptive Large Neighborhood search for school bus routing problem with bus stop selection

M. S. Fallah Niasar
University of Antwerp, Department of Engineering Management, Faculty of applied economics
e-mail: mohammadsaeid.fallahniasar@student.uantwerpen.be

M. Sajadifar
University of Science and Culture, Department of Industrial Engineering

A.H. Tayebi
University of Antwerp, Department of Engineering Management, Faculty of applied economics

1 Introduction

Transporting students to and from a school is a challenging problem for any local government trying to optimize its budget. The school bus routing problem represents a variant of the well-known vehicle routing problem. The goal is to pick up the students allocated to some bus stops and generate routes, including the selected stops, to carry the students to school. Among the many variants that have been made in connection with school bus routing problem, this paper deals just with a single school.

2 Methodology

Several variants of heuristics have been applied for SBRP in which presented basis Local Search context. Local search operators regularly construct moves that create slight changes in the current solution. These moves might change the requests within one route or two different routes simultaneously. There is, however, difficulty with this approach; while the tight constraint to be applied to the problem and implementing the local search operator is less profitable. To cope with this problem, one strategy is to accept infeasible segment of solution space as a new promising area. some studies have addressed that a variety of problems can be solved efficiently if a presented algorithm considers both feasible and infeasible states in its search space, called strategic oscillation ([1]). Indeed, allowing infeasible solution leads to increase chance of escaping from the local optima. Another strategy is to use the large standard move instead of incorporating small moves, called Large Neighborhood search ([2]). Unsurprisingly, the price of employing the latter case may make expensive computing time compared with small standard move one, but very desirable results respect to quality of solution will be obtained. To the best of our knowledge, the application of strategic

oscillation in an SBRP context is new, the methodology of which is well-known to have been successful in solving the different variety of VRP. It is clear that searching in infeasible part of solution space needs to take set of large enough neighborhood structure, helping with the transition from the infeasible to feasible rapidly. For this purpose, in this paper, we propose LNS algorithm that uses the strategic oscillation method, to transition between feasible and part of the solution infeasible solution. Our results demonstrate that the exact method is only able to solve the easiest 43 instances in the reasonable time and is impractical to be employed for larger instances. Therefore, in order to solve the SBRP in a reasonable computation time and to reach near optimal solutions, simple LNS and adaptive LNS, so called ALNS, configurations are developed in this paper.

3 Conclusion

Our experiments are implemented in two steps sequentially: First configuration only incorporates one removal and one insertion heuristic, called simple LNS heuristics. We consider 5 metaheuristics for first configuration including: 'Shaw removal with Basic greedy', 'Shaw removal with Deep greedy', 'Shaw removal with Regret 2', 'Rand removal with Regret 2', 'Worst removal with Regret 2'. Second configuration indicates full adaptive LNS with dynamic weight adjustment, called ALNS. We compare each heuristic configuration in terms of best gap and average gap to best known solution by doing some tests on 104 instances, on small, medium and large instances ([3]). To conclude that from the best gap and average gap point of views that is clear that Shaw removal performs better than other removal heuristics. The results reveal that the ALNS heuristic is able to find better solutions than each simpler LNS heuristics. That is, the simpler heuristic may produce a poor solution in some instance, while that is the art of ALNS to make results well.

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A study of exact methods for container loading problems

Everton Fernandes da Silva
Túlio A. M. Toffolo
Greet Vanden Berghe
Tony Wauters
KU Leuven, Departament of Computer Science, CODeS & ITEC-imec
e-mail: everton.fernandesdasilva@cs.kuleuven.be

The container loading problem, a 3D packing problem, consists of allocating a number of items (usually boxes) inside one or more containers. Different characteristic combinations give rise to different variants of the problem. This study addresses four of these variants: the single knapsack problem (SKP), the single large object placement problem (SLOPP), the multiple heterogeneous large object placement problem (MHLOPP) and the open dimension problem (ODP).

The SKP occurs when there exists a single container and a set of strongly heterogeneous boxes to be placed inside the container. By contrast, the SLOPP arises if there is a single container and a set of weakly heterogeneous boxes to be allocated. Finally the MHLOPP concerns a set of boxes requiring placement inside a set of weakly or strongly heterogeneous containers. Although these three problems originate from the same source, the SKP and the SLOPP's objective is to maximize the container's occupied volume, whereas the MHLOPP's is to minimize the number of containers. These three problems assume that containers have fixed dimensions. In the ODP not all dimensions of the container are fixed. The most common scenario in this variant is where two dimensions are fixed (width and height, for example) and the objective is to minimize the remaining dimension.

This study compares the most significant exact methods proposed in the literature for the four variants of container loading problems considered. These methods include several discrete and continuous mixed integer programming (MIP) models and a specialized branch-and-bound.

Regarding the origin of the MIP models, three were taken from the MHLOPP, two from the SKP and one from the ODP literature. The specialized branch-and-bound was taken from the MHLOPP literature.

These methods are adapted so as to enable a clear comparison using classic benchmark datasets from the literature concerning addressed problems. The benchmark datasets consist of different configurations, enabling the evaluation of the methods in distinct situations. Eight benchmark sets are considered, with five consisting of a small number of boxes (up to 15), one from 5 to 100 boxes and the two remaining of a larger number of boxes (at least 100).

To analyze the methods, the comparison parameters depend on the particular problem type considered. The number of unallocated boxes and total container

volume occupation are the comparison parameters available for the SKP. Since all boxes are already inside the container to begin with in the open dimension problem, the comparison criterion is the value of the minimized dimension. The final results are obtained when the optimal solution is found or the execution time limit is reached.

The results obtained suggest which exact methods perform best for each container loading problem category. These results provide further insight and aid in the development of new formulations and matheuristics for the considered problems.

Acknowledgments

Work supported by the Belgian Science Policy Office (BELSPO) in the Interuniversity Attraction Pole COMEX (http://comex.ulb.ac.be). Editorial consultation provided by Luke Connolly (KU Leuven).

The Transportation Problem with Conflicts

Annette M.C. Ficker
KU Leuven, Centre for Operations Research and Business Statistics
e-mail: annette.ficker@kuleuven.be

Frits C.R. Spieksma
KU Leuven, Centre for Operations Research and Business Statistics
e-mail: frits.spieksma@kuleuven.be

Gerhard J. Woeginger
Lehrstuhl für Informatik 1
e-mail: woeginger@cs.rwth-aachen.de

In the classical Transportation Problem we are given suppliers, each having a supply, and locations, each having a demand. For all possible combinations of supplier and location we are given a unit transportation cost. The goal is to fulfill the demand with minimum cost. This problem is well-known and efficiently solvable.

Many situations in practice have, as a base, this transportation problem. However, additional properties are often present. To illustrate this, consider a setting described in [4], where patients (suppliers) have to be allocated to hospital rooms (locations), with the additional constraint that each room should only contain patients of the same gender. This example gives rise to the so-called Red-Blue Transportation problem (RBTP), where suppliers have a given colour, either red or blue, and no location is allowed to receive supply from both colours. We call a pair of different coloured supply nodes (a pair of patients with different gender) a *forbidden pair*, and further, we call the set of forbidden pairs the *conflict set*. Clearly, if all suppliers have the same colour (and hence the conflict set is empty), then RBTP reduces to the classical Transportation Problem. RBTP is already NP-hard when the supply of each supplier equals 1 and all demand equals 3 [4].

Another example, see [1], comes from storage management where containers (suppliers) need to be placed in rows of a storage yard (locations), such that costs of operations (search, load) is minimized. Some containers are not allowed to be placed in the same row, due to their content or size. Again, two containers that cannot be placed in the same row are called a forbidden pair, and the set of forbidden pairs for a particular row form its conflict set. The resulting situation gives rise to the Transportation Problem with Exclusionary Side Constraints (TPESC). Thus, in the TPESC we are given a set of forbidden pairs (conflict set) for each location. It is not difficult to see that RBTP is a special case of TPESC. The complexity of different variants of TPESC is considered in [3].

Our last example comes from [2], where companies (suppliers) want to promote their products to potential customers (locations). On the one hand, a customer wants to limit the number of promotions received from similar companies, inducing forbidden pairs of companies for each customer. On the other hand, companies want to geographically spread their promotion and therefore limit the number of promotions to customers living close to each other, inducing forbidden pairs of customers. In [2] they call this problem the Conflict-aware weighted Bipartite b-matching problem (CA). Here we are given conflict sets for both locations and suppliers. There is also an edge-capacity; each company may send at most one advertisement to each customer.

The Transportation Problem with Conflicts (TPC) generalizes the all problems mentioned above, by extending the input of the classical transportation problem with a conflict set for each supplier and each location.

Results

We analyze this TPC, and special cases of the TPC by investigating possible structures within the conflict set. We build a *conflict graph* for each location (supplier) as follows: there is a node for each supplier (location) and two nodes are connected if and only if the corresponding suppliers (locations) constitute a forbidden pair. For instance, RBTP can be seen as an instance of TPC where the conflict graph for each location is a complete bipartite graph.

We prove that for many different classes of conflict graphs (bipartite, interval and planar graphs) TPC is NP-hard. We also settle a case left open in [4], and we extend existing approximation results.

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On the economics of circular economies

Juan F. Garcia
KU Leuven, CEDON
e-mail: juan.garcia@kuleuven.be

Johan Eyckmans
KU Leuven, CEDON

Sandra Rousseau
KU Leuven, CEDON

Building on the current European Commission and European Union's Parliament discussion on the Circular Economy package as an emergency response to unsustainable landfill capacity, imported raw material dependence and uncontrolled pollution [1,2], this paper presents a dynamic general equilibrium model in which resource endowments, re-manufacturing, material recovery and extended responsibility policies play a key role in determining the inter-temporal equilibrium of the economy.

Our study of the Circular Economy departs from a decentralized analysis in which material flows and technologies are consistent with both material balance and thermodynamic restrictions, properties usually poorly understood in the environmental economics literature. It is shown that despite laissez-faire linear economies capable of recycling are likely to experiment shortage of raw material and landfill capacity, sufficient economic incentives are naturally activated triggering an endogenous transition to the circular economy. However, this transition is not Pareto optimal, being dominated by allocations achieved via optimal policy intervention.

The research is enriched in 4 directions. First, we show that property rights introduction reduces the complexity of optimal taxation in the circular economy. Second, technology and consumption externalities are included and subsequent optimal policy of extended producer responsibility type (EPR) is derived. Third, a second best analysis is performed for different scenarios when recycling policies are difficult to implement. Finally, as a our major theoretical contribution to the literature, we open the economy and study conditions on the fundamentals that rationally explains why some small economies behave more circular than others. We conclude that, in general, optimal massive recycling depends on the relative importance of domestic productivity, landfill capacity and the environmental footprint of international versus domestic production, challenging the waste management hierarchy as performance benchmark.

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Scheduling the Australian Football League

D. Goossens
Ghent University, Faculty of Economics and Business Administration, Belgium
e-mail: dries.goossens@ugent.be

J. Kyngäs, K. Nurmi, N. Kyngäs
Satakunta University of Applied Sciences, Finland

When measured by attendance, Australian Football is by far the most popular sport in Australia. Accordingly, the quality of the schedule of play is important, as the schedule has a direct impact on revenue for all involved parties. For instance, the number of spectators in the stadia and the travelling costs for the teams are influenced by the schedule, and TV networks that pay for broadcasting rights want the most attractive games to be scheduled at commercially interesting times.

The scheduling problem faced by the Australian Football League (AFL), which consists of 18 teams, is quite challenging. The two main objectives are related to travel distance and breaks. Australia is a big country, which causes extensive travel loads for the teams, especially for the remote teams. For instance, in 2013, the total travel distance was 243,125 km. The AFL wishes to balance total travelling between teams from the same state, without exceeding the current total travel distance. The second objective is to minimize the total number of breaks (if a team plays two home or two away games in two consecutive rounds, it is said to have a break). Achieving these objectives is further complicated by an extensive list of constraints that need to be taken into account, communicated to us by the league authorities.

The AFL scheduling problem has two interesting and relatively novel features. First, the AFL consists of a single round robin tournament (i.e. each team plays against every other team once) complemented with 5 additional matches for each team, which are mixed with the round robin matches (as opposed to e.g. play-off competitions). Integrating additional matches into a round robin tournament is uncommon, but has been studied before by academics in the context of the New Zealand Rugby Union Cup (Johnston and Wright, 2014) and the Finnish Major Ice Hockey League (Kyngäs and Nurmi, 2009). In these competitions, the opponents and the home advantage for the additional matches are fixed before the schedule is created; in the New Zealand Rugby Union Cup teams get to pick their opponents for the additional matches in a media-covered selection event. In the AFL, however, deciding the opponents and the home advantage for the additional matches is part of the scheduling process.

A second interesting feature is the fact that some teams in the AFL have multiple home venues. In addition, two stadia, Etihad and MCG, host almost half of all the matches. Half of the teams play one or more home matches at these stadia, and some teems need to play a minimum number of away matches

at Etihad Stadium. Furthermore, as the AFL is trying to expand the sport throughout the country and even to New Zealand, some of the matches are played in cities and stadia that do not have a permanent home team. Settings with multiple venues have been studied from a theoretical point of view by e.g. Urban and Russell (2003, 2006), de Werra et al. (2006) and Ikebe and Tamura (2008). However, in these contributions, the idea is that the stadia are not linked to any team, and the goal is that each team plays the same number of games in each stadium. We are not aware of any contribution on real-life sport scheduling that deals with multiple home venues.

As the AFL scheduling problem turns out too demanding to solve in a single model, we have developed a 3-phase approach. In the first phase, opponents and home advantage are decided, the second phase assigns matches to rounds, and the final phase decides on the kick-off times and venues. Each of these phases is tackled with an implementation of the PEAST (Population, Ejection, Annealing, Shuffling, Tabu) heuristic, which has proven its value for several other complex real-life problems. The AFL currently uses software from the firm "Optimal Planning Solutions" to craft the schedule. This company creates fixtures for leading competitions across the globe including NFL football, European soccer, the NRL Rugby and Super Rugby. Our goal is to improve on the official schedule, in particular with respect to minimizing and balancing travel distance and the number of breaks. We report on our computational results and compare our schedule with the official schedule for the 2013 season.

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A supply chain network design model to assess horizontal cooperation

Thomas Hacardiaux, Jean-Sébastien Tancrez
Université catholique de Louvain, Louvain School of Management & CORE
e-mail: thomas.hacardiaux@uclouvain.be, js.tancrez@uclouvain.be

Nowadays, companies have to find the right balance between a cost-effective supply chain and a competitive service to their customers. While the oil price and the number of road taxes are persistently increasing, transport planning still leads to incomplete loading of trucks. In response to these issues, some companies turn towards cooperation (Juan et al., 2014). In that respect, two major models can be identified. First, vertical cooperation consists in the collaboration of companies that work at the different levels of the supply chain (e.g. a supplier and a retailer). Second, horizontal cooperation rather consists in collaboration at the same level of the supply chain (e.g. two suppliers working together). This latest approach may in particular integrate competitors who accept to share (partially or entirely) their logistic functions (Cruijssen, Cools and Dullaert, 2007).

The literature on horizontal cooperation discusses several real-life cases and simulation studies of horizontal collaborations. Authors generally acknowledge horizontal collaborations that generate savings. Recent researches have however shown that these savings may have various scales from 5% to 30% (Hageback and Segerstedt, 2004, Frisk et al., 2006). To explain these mixed results, partners' and markets' particularities must be taken into account (Cruijssen, 2006). Transportation costs (Juan et al., 2014), inventory costs (Ergun, Kuyzu and Savelsbergh, 2007), distances (Mason, Lalwani and Bougton, 2007), CO_2 emissions (Pan, Ballot and Fontane, 2013) are some of the parameters that may be integrated. Answering the call for a better understanding of the impact of markets' and partners' characteristics on coalition gain, we conduct a large set of numerical experiments with a location-inventory model, varying several key parameters, to estimate their respective impact on the coalition gain of partnerships. This study also enables us to assess the evolution of transportation, inventory, ordering and safety stock costs at distribution centers and retailers, comparing results of stand-alone companies and horizontal partnerships.

We propose a location-inventory model, in the form of a conic quadratic mixed integer program, to determine the number and the locations of the distribution centers, as well as the delivery network and the inventory decisions. The objective of our model is to minimize the total cost composed of the transportation, inventory, opening, ordering and safety stock costs. To the best of our knowledge, the safety stock cost at retailers and at distributions centers influence the coalition benefits but are never taken into account in the current literature. In our numerical experiments, we consider the supply chain networks of two companies

with independent plants and products. We suppose that each company's supply network is optimal. Our goal is to assess the savings if the potential partners use joint distribution centers and trucks in a new network. We create a large number of instances to determine the impact and the importance of various parameters (holding, order and opening costs, coefficient of variation and trucks capacities). We analyzed 1944 parameter combinations, tested on 5 maps in which retailers' demands and locations are randomly varied. For each parameter combinations and for each map, we compute the optimal solution when two companies work separately and jointly, resulting in 29.160 experiments. Results are obtained with a maximum computational time of 30 minutes and an average optimality gap of 0.25%.

Early analyses show an average total cost reduction of 22% when the two companies are cooperating, in comparison with the sum of the stand-alone costs of companies working independently. Benefits are highly dependent on parameter combinations, as they vary between 15% and 30%. This variation and the important number of experiments allow to understand the impact of some markets' characteristics on the horizontal cooperation efficiency. We analyze the impact of the number of distribution centers owned by companies before the partnership. We also look at the safety stocks at distribution centers and at retailers. Naturally, these stocks increase with the demand uncertainty. However, the growth of the safety stocks at distribution centers is faster in horizontal cooperation than when companies work independently. We obtain an opposite result for the safety stock at retailers, as they increase less when companies cooperate. Finally, we also analyze the possible improvement of the service level, the impact of the trucks' capacity on transportation costs, the improvement of the loading rate and change in the number of distribution centers opened.

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Multi-objective decisions for train load planning

H. Heggen[a,b], K. Braekers[a,c], A. Caris[a]
(a) Hasselt University, Research Group Logistics
(b) Maastricht University
(c) Research Foundation Flanders (FWO)
e-mail: {hilde.heggen, kris.braekers, an.caris}@uhasselt.be

Railway transportation is strongly supported by the European Commission [4] as a means to stimulate intermodal transportation. By significantly raising the efficiency and capacity of rail transportation over long distances, intermodal rail-road freight transport can be encouraged [1]. Caris et al. [3] stress the fact that intermodal transportation has a higher degree of complexity than unimodal transportation, because more transportation modes and consequently more decision makers are involved. The degree of complexity increases even further in the most recent synchromodal concept. Available infrastructure should provide proper support for a seamless integration of the transport modes in order to guarantee a stable and efficient service to the customer.

One important aspect concerns the development of planning systems to provide insights into current available capacity. Furthermore, planners are confronted with a complex booking and transport planning process. Therefore, the system should be able to address the occurrence of uncertain events in order to dynamically plan current transport operations. Whereas most literature focuses on a more general view on capacity, such as route and network capacity, the train load planning (TLP) problem considers a detailed definition of train capacity utilization. TLPs are focused on the assignment of load units to specific locations on an intermodal train, taking into account restrictions on axle, wagon and train weights and other operational constraints if applicable. Automation of this task can provide train planners support during the planning process.

The problem in this paper builds on the problem presented by Bruns and Knust [2]. Weight restrictions in case of wagons with three bogies are added, as well as the fact that wagons are assigned to fixed destinations, with flexible destination terminals for load units depending on the proximity of the unload terminal to the load unit's final destination. In order to optimally utilize the available loading space, three objectives are considered: maximizing train length utilization, scores for assigning load units to a more preferred destination and the number of urgent load units assigned. However, fixing weights to each objective a priori may be a difficult task, as the decision on the most appropriate load plan depends on information which the human operator receives from direct communication with other parties, as well as information on the availability of alternative transport modes. Therefore, a multi-objective approach is proposed. The result of this approach is a pool of possible TLPs with different characteristics, from which planners can choose the most appropriate plan with respect to the current operational circumstances. In this setting, planners have more infor-

mation, for example on the capacity available of overflow trains (trains operated by other parties) for similar transportation services, and can use this information to decide on the most appropriate plan from the pool of good TLPs.

The problem is first solved exactly using the epsilon-constraint method [5] and the trade-offs between the different objectives are analyzed. Because flexible planning is key to a dynamic, synchromodal environment, and regular updates are common, automated planning which provides solutions of good quality in a short amount of computation time is important. Therefore, a multi-directional local search (MDLS) heuristic [6] is proposed. In each iteration of the MDLS, a random solution is selected from the archive of non-dominated solutions and a different local search is performed in the direction of each single objective using the same initial solution. Finally, the archive is updated by adding new, non-comparable solutions to the archive and removing dominated solutions.

The proposed heuristic algorithm is designed to optimally employ the available train capacity and provide a reliable customer service. It can be implemented into existing transport management systems and provide train planners with decision support, while the final decision remains with the human planner.

Acknowledgements

This work is supported by the Interuniversity Attraction Poles Programme initiated by the Belgian Science Policy Office (COMEX project: Combinatorial Optimization: Metaheuristics & Exact methods).

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Heuristics for crane scheduling and location assignment problems in automated warehouses

Sam Heshmati, Túlio Toffolo, Wim Vancroonenburg,
Greet Vanden Berghe
KU Leuven, Department of Computer Science, CODeS & imec-ITEC
e-mail: sam.heshmati@kuleuven.be

Warehouse operational efficiency plays an important role in boosting the supply chains capacity. This study addresses the automated warehouse scheduling problem (AWSP), which entails assigning positions for all incoming requests and scheduling the pickup and delivery activities of cranes. Automated warehouses employ rail-mounted gantry cranes (RMGCs) to move products from an input point to the storage yard and, ultimately, from there to an output point. The objective is to minimize both delay and storage costs. RMGCs operate in parallel throughout the storage yard and have no predefined working areas. Consequently, pickup and delivery activities must be properly scheduled while simultaneously respecting the necessary safety distance between neighbouring RMGCs. The block (location) assignment problem (BAP) and crane scheduling problem (CSP) are two important decision problems affecting the efficiency of automated warehouse operations.

This study proposes a novel approach aggregating these two problems into a one problem and presents heuristics for real-world size AWSP instances. A constructive algorithm and two meta-heuristics were developed to improve the initial constructed solution. Both *sequential* and *integrated* approaches were considered while developing the meta-heuristics. The *sequential* approach first solves the BAP, the output of which is fed into the CSP as its input, while the block assignments are fixed. The *integrated* approach, meanwhile, simultaneously considers both the BAP and CSP which includes all three decisions requiring consideration when processing the requests: assigning a destination and a crane to each request, and sequencing the execution of all requests.

Both the *sequential* and *integrated* approaches initially generate a solution via a greedy constructive heuristic before improving it with a late acceptance hill climbing local search-based meta-heuristic employing multiple neighbourhoods.

Computational experiments are conducted to examine the key factors of the problem and the performance of the proposed heuristics over a generated set of instances.

Acknowledgements

Editorial consultation provided by Luke Connolly (KU Leuven).

Scaling analysis of state-of-the-art TSP solvers

Holger H. Hoos
Universiteit Leiden, Leiden Institute of Advanced Computer Science
Thomas Stützle
Université libre de Bruxelles (ULB), IRIDIA, CoDE, e-mail: stuetzle@ulb.ac.be

In this talk, we will give an overview of our work on the analysis of the scaling behavior of high-performing exact and heuristic algorithms for the traveling salesman problem. For the empirical scaling analysis we have used a novel approach, which is applicable to solvers for many other problems. Among the TSP solvers, we have considered concorde [1, 2], the state-of-the-art exact TSP solver and two state-of-the-art heuristic algorithms, namely Helsgaun's implementation of the Lin-Kernighan heuristic versions 1.3 and 2.0 [4, 5] and the evolutionary algorithms with EAX-crossover by Nagata and Kobayashi [8]. We show that (i) for exact algorithms the empirical median run-time required to solve random uniform Euclidean (RUE) instances scales using a root-exponential scaling, (ii) the fraction of the time taken by exact algorithms to find the optimal solution is a large fraction of the overall run-time and growing with instance size, (iii) the heuristic algorithms scale better than exact algorithms when considering the finding times of optimal solutions in terms of constants and some also in terms of scaling law, and (iv) automatic configuration can have a significant impact on the scaling behavior of at least the heuristic algorithms.

Most of the presented work is published in the form of journal or conference publications or is currently under review for journal publication. The relevant references are included below [6, 3, 7].

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Making exit costly but efficient : Optimal exit timing in political unions

M. Huysmans
KU Leuven, LICOS Centre for Institutions and Economic Performance
e-mail : martijn.huysmans@kuleuven.be

This article presents a decision-theoretical analysis of exit clauses in currency unions and (con)federal systems. In such unions, members' benefits depend on their characteristics and on the state of the world. If a member's benefits become negative, it may wish to exit. Using a dynamic stochastic model based on real option theory, we show that state-contingent exit penalties can enable socially efficient dissolution of the union. Even if exit penalties cannot be made state-contingent, they may still enhance social welfare by preventing secession wars. This finding runs counter to the dominant point of view in the literature that exit clauses should be avoided in federations. To demonstrate the validity of the theory, we show how it can explain the dynamics of the breakup of Yugoslavia.

1 Basic features of the model

In our model, a member's benefits from a political union are determined by its type θ and its state x. Because of changes in the state of the world, a member's benefits may go up or down. Mathematically, we assume that the state of each member follows a Brownian Motion. If a member's benefits become negative, i.e. it is in a low state, it may wish to exit. Using real option theory, we derive a member's optimal exit state. The higher a member's type, the higher exit costs, and the higher the variance of benefits, the lower the state can drop until it becomes optimal to exit.

When a member exits, the benefits for the other members of that member being in the union are also stopped. From a social efficiency perspective, exit should occur if and only if it generates value taking all members' benefits into account : this is the principle of "efficient breach" in contract law. In political unions, if exit costs are too low, a member may withdraw from a union even if that is harmful from a social perspective combining all members' benefits.

2 Modes of exit

Exit costs depend on the mode of exit. If a political union has an ex-ante negotiated exit clause, exit can occur on the basis of such a clause. Exit clauses can contain several conditions, among which we analyze exit penalties, one-off costs, and notice periods. If the costs of exit according to the exit clause are low, and it occurs while other members are benefiting a lot from the union, those

other members may try to prevent exit forcefully. In practice, such prevention of legal exit will carry both military costs and reputational costs, especially for democracies. If there is no exit clause, or the exit cost is high, exit may also occur unilaterally. The costs of such unilateral exit consist of tangible costs (such as military expenses) and reputational costs (which depend on the international recognition of the exit). A third mode of exit is through ex-post negotiation, although this can be expected to be difficult because of vested interests and frictions to negotiations.

3 Discussion of findings

Our findings run counter to the dominant point of view in the literature that exit clauses should be avoided in federations. The argument that exit clauses necessarily decrease the stability of an agreement is unsound : without exit clauses, exit may still occur unilaterally or through a negotiated exit. The inclusion of exit clauses when political unions are created can improve ex-ante social welfare. In particular, costly state-contingent exit penalties can enable socially efficient exit even if negotiating exit is difficult. If exit penalties cannot be made state-contingent, fixed exit penalties can still increase social welfare by avoiding secession wars.

Given our results, one may wonder why exit clauses are not more prevalent in real-world political unions. We discuss four main reasons here. First, the politicians negotiating political unions may wish to tie their successors' hands. In our model, we assumed that each member of the political union could be represented as a unitary actor. In practice, political unions may have heterogeneous effects on different parts of the population within one member. If that is the case, politicians whose electorate favors the agreement may want to prevent exit in the future by not having an exit clause.

Second, political unions may not be rationally designed. This may be especially true for federal countries which have existed for a long time. But even for modern federations and currency unions there may be a norm against exit clauses because they are perceived as going against the spirit of collaboration embedded in such unions. Such a norm may also explain why most real-world examples of exit clauses (such as the EU's Article 50) have no exit penalties, in spite of the necessity of exit costs to achieve socially efficient exit decisions.

Third, exit clauses may not be prevalent in the real world because some of the conditions of our theory do not hold. In particular, the cost of a secession war may be uncertain. Fourth, powerful members may be able to impose their terms upon the other members. Given favorable substantive terms of the union, they would expect to benefit a lot from the agreement. In turn, this would lead them to prefer a high exit cost for the other members. Expecting to be able to renegotiate easily if the agreement would ever stop being beneficial to them, they may prefer not having an exit clause altogether, and impose this upon the other members. Empirical research is needed to assess the true role of each of the four reasons mentioned above.

A heuristic approach to the truck scheduling problem in a tank terminal

E.-J. Jacobs, J. Verstichel, T.A.M. Toffolo,
T. Wauters and G. Vanden Berghe
KU Leuven, Department of Computer Science, CODeS & imec-ITEC,
e-mail: evertjan.jacobs@cs.kuleuven.be

Tank terminals offer storage for products such as mineral oils, gases and chemicals. Transportation of these products to and from the terminal is the clients' responsibility, who outsource such requirements to external contractors. Inefficient transportation unit scheduling at the terminal results in a longer amount of time spent at the loading yard and higher client cost. Therefore the primary goal is to improve client satisfaction by reducing total time spent at terminal loading areas.

Although transport units such as trucks, railcars, barges and sea vessels arrive at the terminal, this abstract's focus exclusively concerns trucks. The tank terminal referenced by this abstract is Oiltanking Stolthaven Antwerp NV (OTSA). The loading area for trucks, also called the loading yard, consists of multiple parallel loading racks positioned in series. The loading yard's layout implicitly introduces a blocking constraint: two trucks stationary at both sides of the middle lane may prevent other trucks from reaching their destination. When no other route to the destination exists, the truck is blocked until one of the stationary trucks moves. The time that trucks remain stationary depends on operator availability. A loading activity on a truck consists of a sequence of tasks which must be assigned to operators. Trucks may leave their position when the last task has been completed.

Blocking concerning trucks in terminals has not been studied in the academic literature. For example, the vehicle scheduling-location problem in a container terminal exclusively focuses on location assignment without taking blocking into account.

This work introduces a heuristic approach for the truck scheduling problem. The heuristic first determines each truck's loading position, route and dispatch sequence position. Given this information, a serial schedule generator creates feasible solutions while respecting all constraints. Examples of such constraints include how the current truck may only be dispatched when no truck is currently loading on its route or how tasks should only be undertaken and completed by available operators with the necessary skills. The cost associated with the schedule is the total blocking time, which must be minimized. The best solution is searched for using move operators such as shift trucks within the dispatching sequence or selecting a different route for the given truck.

Experiments are conducted using real-world instances provided by OTSA. The primary goal is to find the best data structure for the fast generation of new

schedules, since the algorithm will be employed by tank terminal schedulers in a dynamically-evolving environment.

Acknowledgement: This work was supported by Agidens, Oiltanking Stolthaven Antwerp NV (OTSA), the Belgian Science Policy Office (BELSPO) in the Interuniversity Attraction Pole COMEX (http://comex.ulb.ac.be) and Leuven Mobility Research Center and funded by research project 140876 of the Institute for the Promotion of Innovation through Science and Technology in Flanders (IWT-Vlaanderen). Editorial consultation provided by Luke Connolly (KU Leuven).

Risk-averse assortment and pricing decisions in production/inventory Systems

H. Jalali
KU Leuven, Research Center for Operations Management
e-mail : hamed.jalali@kuleuven.be

I. Van Nieuwenhuyse
KU Leuven, Research Center for Operations Management
e-mail : inneke.vannieuwenhuyse@kuleuven.be

Despite the rich literature on assortment planning, many closely related and managerially relevant problems have not been addressed sufficiently and require more research. According to Kok et al. (2015), joint pricing and assortment planning is one of these areas. In recent years, several papers have considered this problem in different settings but all of them assume risk-neutral decision makers which are insensitive to profit variability. In practice, however, decision makers are often risk-averse : they are willing to trade off lower expected profit for smaller risk (Simchi-Levi et al., 2005 ; Chen et al., 2007 ; Choi et al., 2011).

In this article, we build further on Jalali et al. (2016) to analyze the impact of risk aversion on the assortment and pricing decisions of a make-to-stock manufacturer with a given finite production capacity. The finished products are differentiated along a quality index. The inventories of finished products are reviewed periodically, and replenishment orders are sent to the production facility. Replenishment lead times are thus endogenously generated by the finite-capacity production system and, consequently, are load-dependent (i.e., we have a production/inventory setting). The replenishment lead time is thus correlated with the demand which is directly affected by typical marketing decisions such as assortment and pricing.

The manufacturer needs to decide on price, quality and inventory levels of the products offered. In Jalali et al. (2016), the objective of the manufacturer is to maximize the expected profit per period (revenues from sales, minus material, inventory holding and backorder costs) which is appropriate for risk-neutral decision makers (Chen et al., 2007). In this paper, we incorporate risk aversion into the analysis of Jalali et al. (2016), using variance of profit per period as the risk measure. Variance of profit (or cost) has been extensively used in the literature as a measure for risk (Chiu and Choi, 2016).

As in Jalali et al. (2016), we consider two products and fix the quality of the first product. The goal of the decision maker is to set the price levels of both products, the quality of the second product, and base-stock inventory levels to obtain a desired trade-off between expected profit and profit variance. The desired trade-off depends on the risk aversion of the decision maker ; we thus focus on solutions that constitute the mean-variance efficient frontier (i.e., Pareto frontier).

These solutions are efficient because it is impossible to increase their expected profit without increasing their profit variance. Our main objective is to see how the price, quality, and inventory decisions of the firm change as it goes from the risk-neutral extreme of the Pareto frontier to more risk-averse solutions.

The full Pareto frontier can be estimated by exhaustive simulation : we then simulate the profit mean and variance of all possible solutions to detect the points that lie on the Pareto frontier. This approach, however, may take very long time (especially when the simulation itself is time-consuming). We thus propose a Kriging-based approach, which enables us to obtain good representations (i.e., approximations) of the full Pareto frontier with significantly lower simulation budget. The managerial insights obtained from this representation are the same as the ones obtained from the full frontier, and we summarize them as follows.

We show that high congestion of the production facility results in high variability in inventory-related costs and thus result in high profit variance. A more risk-averse firm, thus, sets a tighter control over the utilization of the production system by charging higher prices especially for the higher quality product (which is also more time-consuming to produce). We illustrate that reducing the profit variance through simultaneous increase of the price of both products may not be Pareto optimal. The relation between risk aversion and the quality levels is also not monotonic. Finally, seeking very low profit risk may come at the cost of considerably lower market coverage for the firm.

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A branch-and-price algorithm for parallel machine scheduling using ZDDs and generic branching

D. Kowalczyk, R. Leus
KU Leuven, ORSTAT, Faculty of Economics and Business
e-mail: daniel.kowalczyk@kuleuven.be

We tackle the parallel machine scheduling problem with m identical machines for which we minimize the total weighted completion time. We denote this problem by WCT. This problem is NP-hard for two identical machines. We use different techniques that were developed in previous papers and extend some of them. We use zero-suppressed binary decision diagrams (ZDDs) to solve the pricing problem associated to the branch and price (B&P) algorithm for a partition formulation of WCT that was introduced in [2]. ZDDs give us the opportunity to apply generic branching rules for this type of problems. Morrison et al. [1] develop a B&P algorithm for the vertex coloring problem (VCP). They also use generic branching rules, but they branch on the variables of the set covering formulation of VCP. In our work we show that other generic branching rules for B&P, such as the Ryan-Foster branching rule, can also be used by adding the constraints to the pricing problem instead of adding constraints to the variables of the partition formulation. Other enhancements that improve the efficiency are:

- dual-price smoothing as a stabilization method for the column generation phase of the algorithm; and
- Farkas pricing to handle infeasibilities that can emerge after adding constraints to the pricing problem.

We report computational results that show the effectiveness of the algorithmic enhancements, which depends on the characteristics of the instances. To the best of our knowledge, we are also the first to use ZDDs to solve the pricing problem in a B&P algorithm for a scheduling problem.

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Optimizing raw materials and finished goods safety stocks in a production network under guaranteed service approach

Kunal Kumar
Ghent University, Faculty of Economics and Business Administration
e-mail : kunal.kumar@ugent.be

Tarik Aouam
Ghent University, Faculty of Economics and Business Administration
e-mail : tarik.aouam@ugent.be

The safety stock placement problem under the guaranteed service approach (GSA) determines the placement and amount of safety stocks to hold at different stocking locations of a supply chain. We consider a network of production facilities. Each facility includes a processing unit, inventory of raw materials, and inventory of produced items or finished goods. A facility may hold safety stocks for both raw materials and finished goods. The objective of this work is to identify the production stages that hold safety stocks, the allocation of safety stocks between raw materials and finished goods, and the release policy of raw materials into processing units in order to minimize systemwide inventory costs while meeting a target service level. We name this new problem as the *safety stock placement and allocation* (**SSPA**) problem.

A spanning-tree network of production facilities that serves an external demand of a single end-product from stock is considered. Along the assumptions of GSA, demand over any period is bounded. We assume that demand interarrival times are independent and follow a general probability distribution. Replenishment of a production stage is triggered by finished goods inventory according to a periodic review base stock policy, with a common review period between stages. Supplier stages quote a guaranteed service time within which the goods must be shipped to the customers. After stipulated transportation times the goods arrive at the raw materials inventory, which are then released following a base stock policy with delay. The allocation of safety stocks within a stage influences the delay parameter of the base stock release policy. In fact, due to the variability of demand during the incoming service time (replenishment lead time), a stage must carry safety stocks or delay release to ensure availability of required raw materials. When no raw material safety stocks are held, a delay is required between the occurrence of demand and the release of raw materials to the workstation. It follows that a key tactical planning decision is the release delay parameter. Based on these system settings and assumptions, a mathematical formulation of the **SSPA** is presented.

Our analysis suggests that holdings for raw materials follow an *all-or-nothing*

rule, where a facility either hedges raw materials for the demand during the entire incoming service time or holds no safety stock at all. Concerning the release policy, this translates to one of the two possibilities - either an immediate release or a delay equal to the total incoming service time. We find that a facility may hold raw material safety stocks only under the following conditions - *a)* if a facility procures raw materials from a supplier external to the supply chain under control, *b)* if it requires a positive transportation delay between shipment and receipt of raw materials, and *c)* if a stage rations its raw materials among several suppliers. In all other cases, it is optimal to hold safety stocks only in the form of finished goods. Furthermore, we find conditions on holding costs, production lead times and incoming service times that will determine the optimal allocation between raw materials and finished goods safety stocks when a stage may hold safety stocks in both the forms.

Based on these findings, an existing dynamic programming algorithm for spanning-tree networks is extended to solve **SSPA**. The algorithm is then used to test the propositions on a real-sized instance with 31 production facilities. Experiments confirm the claims made in this paper. Further, we evaluate the savings yielded by employing safety stocks in the form of both raw materials and finished goods, as opposed to holding only finished goods safety stocks. Results show that the magnitude of savings depends on the value added at a stage, and also the transportation times between stages.

Modelling and simulation of the ballistic protection limit V50 by exact sampling of an integrated Brownian motion process with drift

B. Lauwens, I. Hermosilla, J. Gallant
Royal Military Academy (Brussels)
ben.lauwens@rma.ac.be, itsaso.hermosilla@rma.ac.be, johan.gallant@dymasec.be

The evaluation of a ballistic protection against a projectile is constantly creating new challenges for scientific research on means of protection as it is characterized by dispersion. In this paper a stochastic model is presented for the evaluation of the expectation and the variance of the ballistic protection limit V50 and associated limits.

The ballistic protection limit V50 is defined as the velocity at which 50% of identical projectiles will perforate a ballistic protection and logically at which 50% will be defeated by the armor. Until now this limit was typically estimated by one of the four following methods accepting that the penetration probability obeys a normal distribution; Langlie, Probit, Kneubuehl or the Stanag 2920.

Langlie and Probit are based on the maximization of the likelihood function [3]. The mean (V50) is deduced by iteration afterwards. However, the difference between them is the fact that Probit selects the two values of V50 and the standard deviation that makes the likelihood function maximum.

Kneubuehl [1] works grouping the data records in classes upon the velocity and determinates the perforation probability of each class. Then, a cumulative density function of the normal distribution is fitted through the new shooting samples. Nevertheless, the imperative need of operating with these intervals is a disadvantage.

Finally, the Stanag 2920, calculates de V50 by averaging the six velocities that compiles the three lowest giving complete perforation and the three highest giving no perforation taking into account that they stay within a range of 40 m/s. This procedure is relatively easy but returns only the mean value of penetration velocity.

Furthermore, the experimental procedure to produce a large amount of samples in order to be sure of the accuracy of the method chosen is very expensive and time consuming. So, the main drawback it is indeed the necessity of repeating the same impact test under the same exact conditions several times. Consequently, replacing a real firing session by a simulated one becomes the objective of this study.

The slowing down of a projectile can be modelled by the following stochastic differential equation (SDE)

$$V(t) = V_0 - \int_0^t \mu(V(t))dt + \int_0^t \sigma(V(t))dWt(t)$$

where μ is the average slowing down, σ its variance and W(t) is the standard Brownian Motion process. To match both the coefficients μ and σ to the experimental results an inverse problem has to be solved.

First, an approximate numerical solution based on the Euler-Maruyama [2] method including variance reduction techniques was obtained. But, only a very small time step allows an accurate evaluation and it introduces a large computing time.

Therefore an efficient sampling procedure of SDE paths with varying parameters is needed. The following novel algorithm is proposed in this paper:

1. Calculate the end point V(t)=0 by sampling the first passage time distribution;

2. The skeleton of intermediate points is based on scaled Chebyshev [5] points of the second kind:

(a)Using the properties of the Chebyshev polynomials new points are chosen which are situated between previous points;

(b)For each new point a Brownian Motion process is sampled conditioned by the values of the left and right neighbouring points and by considering physical limitations;

(c)The distance travelled by the projectile is evaluated by the Clenshaw-Curtis[4] quadrature;

3. Once the integration is converged, the thickness of the armor is compared with the distance travelled by the projectile allowing a match with the experimental data (perforation / no-perforation).

The novel algorithm is in orders of magnitude faster and makes the solution of the inverse problem feasible. Based on the estimated parameters, more challenging limits, the ballistic protection limit V1, i.e. only 1% of perforation, can be computed. It is important to know that no experimental setup is capable of predicting the expectation and the variance of this ballistic protection limit.

The programming language in use for this technical computing is the high-level dynamic language Julia licensed under the free software MIT license (Massachusetts Institute of Technology).

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On the efficiency of local electricity markets: a bilevel optimization approach

H. Le Cadre
EnergyVille research center, Genk, Belgium
e-mail: helene.lecadre@vito.be

The development of Distributed Energy Resources (DERs) offers new sources of flexibility for the power system. The goal of this article is to compare the efficiency of two coordination mechanisms for the Distribution System Operator (DSO) and the Transmission System Operator (TSO): a centralized Ancillary Service (AS) market fully operated by the TSO and distributed AS markets operated locally by DSOs.

In a *centralized AS market* model, the TSO contracts DER directly from DER owners connected to the distribution grid. DER are aggregated by the intermediate of an aggregator, also called Flexibility Service Provider (FSP). The centralized AS market can be modeled as a standard optimization problem under distribution network constraints where the TSO takes the role of the global coordinator.

On the contrary, in *local AS markets*, the TSO can contract DERs indirectly. This happens after the DSO, via a local market, has aggregated these resources, and has transferred them to the TSO. As a consequence, there is a separate local market managed by the DSO. Resources connected to the distribution grid can only be offered to the TSO via local markets, taking into account the distribution network constraints. Such hierarchical models in which agents have conflicting interests while sharing network constraints belong to the stream of literature called *networked Stackelberg competition* [7]. Failures observed in most of these marketplaces in digital economics for example, increase the need for introducing a centralized authority to coordinate the involved agents.

In our article, we consider a stylized AS market where the bids take the form of either *simple quantity* offers or *block quantity* offers that are subject to intertemporal constraints. We also take into account the distribution network through an idealized linear DC power flow model.

Stackelberg games are hierarchical games involving a leader and possibly multiple followers; the leader taking the followers' optimal reaction into account when optimizing his strategy. Such games are traditionally formulated as bilevel optimization problems [1, 2]. Extension to multi-leader multi-follower games in which a collection of leaders compete in a non-cooperative game constrained by the equilibrium conditions of another non-cooperative game amongst the followers is still considered as a challenging problem in the optimization and game theory communities [4]. This article is a first step towards a more standardized multi-leader follower game representation and the development of appropriate methods to solve them for electrical engineering problems.

Lots of applications of multi-leader follower games can be found in the electricity market literature. In [5], we provided a multi-agent based representation of suppliers and generators that interact in a certain number of geographic demand markets, organized as two tiered systems. Assuming rational expectation of the agents with respect to the outcome of the real-time market, existence and unicity of subgame perfect Nash equilibrium are investigated. Strategic behaviors of agents have also been considered in [6, 3]. In these papers, the authors considered respectively a strategic power producer and an aggregator that bid into the day-ahead electricity market with the objective to maximize their profit and minimize charging costs respectively, while anticipating the market clearing, behavior and data of rival producers and consumers.

In this article, we aim, through a stylized model of centralized and local (decentralized) AS markets, at (i) providing a mathematical model for each of these market designs, (ii) characterizing the existence and unicity of solutions for each of these market designs, (iii) quantifying the *efficiency* of local electricity markets (cleared either simultaneously or sequentially) with high shares of renewables, with respect to the centralized market design using the *Price of Anarchy* as performance measure. Finally, a case study is provided to quantify the impact of the share of renewables on the Price of Anarchy and on the existence of subgame perfect Nash equilibrium for the two market designs.

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The Inventory-Routing Problem with Transshipment

W. Lefever
Ghent University, Department of Industrial Systems Engineering and Product Design
e-mail: wouter.lefever@ugent.be

E.H. Aghezzaf
Ghent University, Department of Industrial Systems Engineering and Product Design
e-mail: elhoussaine.aghezzaf@ugent.be

K. Hadj-Hamou
Grenoble Alpes University, CNRS, G-SCOP
e-mail: khaled.hadj-hamou@grenoble-inp.fr

B. Penz
Grenoble Alpes University, CNRS, G-SCOP
e-mail: bernard.penz@grenoble-inp.fr

1 Introduction

The Inventory-Routing Problem (IRP) is a mathematical problem that seeks to integrate inventory management and transportation planning and optimize the costs of both subsystems simultaneously. Since the introduction of the IRP, the literature on the topic has grown enormously. Recent literature reviews [1] point out the future need for more flexible models to handle uncertainty.

One of the interesting variants that allows to introduce flexibility in the distribution plans in the Inventory-Routing Problem with Transshipment (IRPT). In this problem not only the supplier can deliver goods to the customers, but also transshipments between customers or between the supplier and a customer are possible. These transshipments are carried out by a subcontractor. The objective is to determine the quantities delivered to all customers by both the supplier and the subcontractor in the different periods of the planning horizon while minimizing the total cost.

2 Model

2.1 Valid Inequalities and bounds

Since the introduction of the IRPT a number of valid inequalities have been proposed in Coelho and Laporte [2]. These inequalities act mostly on the inventory

management part of the problem. Based on these inequalities new inequalities are derived for the inventory management component of the problem. We demonstrate how the new valid inequalities dominate the original valid inequalities.

Furthermore, we strengthen the lower and upper bounds of the continuous variables in the model, the inventory variables and the quantity variables. We demonstrate how this results in the simplification and the elimination of a number of variables and constraints.

2.2 Dantzig-Wolfe Decomposition

Next to the addition of new valid inequalities, we were also able to reformulate the problem using the Dantzig-Wolfe decomposition framework. The resulting pricing subproblem is an NP-complete problem. Therefore, the Dantzig-Wolfe decomposition is not suited to solve the IRPT to optimality. However, the Dantzig-Wolfe linear relaxation provides a good lower bound on the problem. We demonstrate how this bound can be improved by adding the new valid inequalities to the Dantzig-Wolfe decomposition and how the solution time of the pricing subproblem can be accelerated by adding certain particular solutions a priori to the column generation algorithm.

3 Preliminary Results and Perspectives

Our preliminary results show that adding the valid inequalities accelerates the solution time of the benchmark instances in literature. It also shows that the Dantzig-Wolfe decomposition linear relaxation provides a good lower bound on the problem. We believe that further investigation of the routing part and the combined inventory-routing part of the problem will lead to stronger formulations which accelerate the branch-and-but procedure even more.

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Performance measurement of a rotavirus vaccine supply chain design by the integration of production capacity into the guaranteed service approach

S. Lemmens
KU Leuven, Research Center for Operations Management
e-mail: stef.lemmens@kuleuven.be

C. J. Decouttere
KU Leuven, Research Center for Operations Management

N. J. Vandaele
KU Leuven, Research Center for Operations Management

M. Bernuzzi
GlaxoSmithKline Vaccines

Previous research has integrated multi-echelon inventory management into the design of a responsive supply chain by the use of the guaranteed service approach. We build further upon this work by integrating the production capacity and product flow to minimize the supply chain's inventories. The production capacity is modeled with a queuing network to handle the variability of the batch production processes as well as the demand variability. We test and validate our model with adapted instances from literature and apply it to the rotavirus vaccine supply chain. This vaccine supply chain is seen as complex on the manufacturing side as well as on the distribution side. For our industrial application we show how this work is embedded in a scenario approach and the contribution of our model to evaluate a single scenario according to multiple performance indicators. For this paper, our scenarios consist of different lead time reduction programmes and varying demand levels. We demonstrate how to extract the best performing scenario.

Termination criteria for metaheuristics: Is computation time worth the time?

Pieter Leyman, Patrick De Causmaecker

CODeS, Department of Computer Science & imec-ITEC, KU Leuven KULAK
e-mail: pieter.leyman@kuleuven.be, patrick.decausmaecker@kuleuven.be

An important issue in metaheuristic research concerns the performance evaluation of different techniques and the lack of any agreed upon manner to do so [3]. The most commonly used termination criterion is the allowable computation time. One can, however, wonder how valuable computation time is when comparing approaches coded on different machines and by different researchers.

Assume as part of a fictitious example, that we wish to show the added value of a new type of local search operator X for the traveling salesman problem (TSP). We claim that it allows for greater insight in the problem characteristics, and as such can lead to a better algorithm performance. To validate our claim, we compare the results of the currently best performing metaheuristic approach (MH) with our results, based on the exact same algorithm but with the new operator X (MH-X). Assume that we have coded MH in the exact same manner as described in the previous research, that we use the same (publicly available) data, and that we employ the same termination criterion of 1.0 s. Table 1 displays the results of the comparison in terms of average objective function value (Av. obj.) and average CPU time (Av. CPU). Based on the results in the table, we would be hard pressed to convince anyone that our approach is worth its salt.

	MH	**MH-X**
Avg. obj.	212	211
Avg. CPU	1.0	1.0

Table 1: Comparison of results version 1.

One could, however, wonder how fair the comparison in the table is. To that end, assume that the MH results were also reported based on a number of schedules (#Sched) stopping criterion [2]. This criterion is based on the assumption that a similar computational effort is required to construct a schedule in most heuristics. In the TSP, we assume that a schedule corresponds to the construction and evaluation of one tour. Swapping for instance two nodes in the constructed tour increases the number of schedules by an additional $2/n$, with n the number of nodes.

Table 2 shows the results for MH with a stopping criterion of 5000 schedules, and compares with MH-X for 1000, 5000 and 10,000 schedules. Now we can conclude that our operator X does indeed allow for a better performance than MH (Avg. obj. of 196 versus 211 for 5000 schedules, p-value < 0.001 based on a paired-samples t-test).

	MH	**MH-X**		
Avg. obj.	211	215	196	189
Avg. CPU	1.1	0.3	1.7	3.6
#Sched	5000	1000	5000	10,000

Table 2: Comparison of results version 2.

From a computation time perspective, we can only conclude that we either used a computer with a slower processes than the MH paper (indeed, a Dual Core 2.6 GHz versus a Quad Core 2.8 GHz processor), or that our code was written in a less efficient manner (difficult to determine if code MH not publicly available). And this brings us to the main point; it is important to report results in a way independent of the processor speed and coding expertise. In doing so, the focus of algorithm performance can shift towards *algorithm* rather than *code* efficiency. During our talk, we will further illustrate the added value of this approach with two problems from literature.

It is crucial to stress that our goal here was not to suggest *some* criterion just to show that operator X has an added value (or to promote an up-the-wall game for that matter), but rather to come up with a fair and independent manner to evaluate metaheuristic performance [1]. Whereas the number of schedules criterion most likely does not constitute the Holy Grail in this respect, we do believe it allows for a step in the right direction, and as a result should at least be considered together with the more commonly used computation time criterion.

Acknowledgements: This research was supported by the Belgian Science Policy Office (BELSPO) in the Interuniversity Attraction Pole COMEX.

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Modeling a materials feeding system in a hospital operating room: a case study

V. Limère
Ghent University, Department of Business Informatics and Operations Management
e-mail: veronique.limere@ugent.be
L. Bonczar

Supplying systems with continual material needs is a well-studied phenomenon in the industrial and systems engineering literature. There are four main policies for the delivery of materials: line-stocking, Kanban, kitting and sequencing. Case studies in literature address industrial environments such as automotive manufacturing [1, 2] or electronic circuit board manufacturing [3]. On the surface, the material delivery system in hospital operating suites contains many similarities to the material delivery systems in industrial settings. This research will first characterize the specificities of the materials feeding methods used in most hospital operating room systems. Secondly, it will present a model of the operating room material feeding system based on modeling techniques presented in the industrial and systems engineering literature. Finally, it will present an application of the decision model to a case study and the results of the model.

Three material feeding policies are seen in practice. The first one regards delivery of the necessary parts on a case cart. This option is similar to kitting in an industrial context, as the required parts are preselected before the start of the surgery. Secondly, some parts are stored in bulk, either in electronic cabinets within the operating room, or on open shelves in a core room, dedicated to a number of operating rooms. Finally, some items are delivered ad hoc, only if requested by the medical staff. In this latter case, parts can be delivered by hand by a supply technician, or sent via a vacuum tube system.

A quantitative model is proposed in order to assign the right policy to a variety of materials given the system's constraints, while minimizing total material handling costs. The model is a binary integer programming model and the cost function consists of four parts: in-room part retrieval, internal transport, case cart preparation, and replenishment costs.

To test the model, data was gathered from an academic medical center's operating room suite in Virginia, USA. The case study was performed under the authority of the hospital administration and was performed in close contact with system stakeholders: clinicians, administrators and ancillary staff. Data from the hospital's inventory management system, human resources information on labor costs, access to the operating room facility's layout schematics, and an accurate set of time-motion studies were required. The model was solved using Gurobi 5.6.2. and results were compared to the as is situation. The model showed that a cost savings of \$31,000 (a 15% improvement) annually could be attained through

a reassignment of parts' materials feeding policies.

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Improving an Incomplete Road Network given a Budget Constraint

Corrinne Luteyn
KU Leuven, Leuven Mobility Research Center - CIB
e-mail: corrinne.luteyn@kuleuven.be

Pieter Vansteenwegen
KU Leuven, Leuven Mobility Research Center - CIB

In this research, we look for savings that can be obtained when a (public) transport company or a logistic player has the ability to discuss road network improvements with the traffic manager. We assume that there is a fixed budget available to improve a road network. Within this given budget, the logistic player can suggest a set of adjustments in the network to the traffic manager. In this research, three different improvements are considered. The first improvement is (re-)opening an existing road that was currently closed for the vehicles of the logistic player. This existing road might be for example a pedestrian street which will be (re-)opened for the logistic player. Another possibility is to widen a road between two locations, while the third possibility is the transformation of a road into a one-way street with a higher speed.

The main goal of this research is to develop a procedure to find the best set of improvements in an existing road network, which minimizes the total travel time of the vehicles of the logistic player in the network. The construction of routes for the vehicles of the logistic player can be seen as variant of the Vehicle Routing Problem (VRP). In this variant, the considered network is incomplete, which means that a direct path is not always available between each pair of locations. Furthermore, only a selection of the known customers has a positive demand and should be served by a vehicle. This variant is called the Steiner Vehicle Routing Problem (SVRP) and is introduced in [1]. Note that in the SVRP, only the routing of the customers is considered, which means that the determination of the best set of improvements is not included. In order to determine the best set improvements of a road network, we introduce the Steiner Vehicle Routing Problem with a Budget Constraint (SVRPBC). Since the group of known customers with a positive demand varies from day to day, this best set of improvements is determined over a set of days. Based on the mathematical formulation for the SVRP, presented in [1], we introduce a Mixed Integer Programming formulation for the SVRPBC.

To solve the SVRPBC for instances of realistic size, we present two different heuristics. The first heuristic is an extension of the Two-Phase Heuristic to determine the best single improvement of an incomplete road network, presented in [1]. This Extended Two-Phase Heuristic (ETPH) consists of the same two phases as the Two-Phase Heuristic, the construction phase and the analysis phase.

During the construction phase, routes for the vehicles in the original network are constructed using a Variable Neighborhood Search (VNS). The applied VNS is presented in [1]. In the second phase of the ETPH, the constructed routes are analyzed to estimate the benefits of all possible combinations of improvements within the given budget. The benefit of a set of improvements is estimated to be equal to the sum of the benefits of the single improvements in that combination. In contrast to the Two-Phase Heuristic, the ETPH is extended with a testing stage. This testing stage is necessary, since the improvements of a set can interfere with each other. The realized total benefit of the set can be larger or smaller than the sum of the benefits of the single improvements due to this interference. This ETPH requires that all possible combinations of improvements within the given budget are determined. Since this is time and memory consuming, we present a second heuristic to solve the SVRPBC.

The second heuristic is an Adaptive Large Neighborhood Search (ALNS) [2]. This ALNS has a main structure based on a Simulated Annealing (SA) algorithm, where the next solution is generated by a large neighborhood. This large neighborhood consists of a set of destroy and a set of repair methods. These destroy and repair methods are unique for this problem, since in this case, the best combination of improvements should be determined instead of the best routes for the vehicles. After the generation of a new solution, the costs of this solution is determined by a VNS.

To test of the performance of both heuristics, we used 16 of the benchmark instances which are presented in [1]. All these benchmark instances are based on a symmetric incomplete road network of 150 possible customers and a depot. The number of customers in these 16 instances is equal to 20 to 51, while the number of vehicles ranges from 1 to 4. Preliminary tests on these benchmark instances show that by improving the network, the total travel time of the vehicles in the modified network can be decreased by on average 5 %. Furthermore, we can conclude that both heuristics have the same performance, while the ALNS is faster, since the determination of all possible combinations within the given budget is not required. The 16 larger benchmark instances of [1] can only be solved by the ALNS, due to the required determination of all possible combinations in the ETPH. The decrease in total travel time is in these larger instances on average smaller than in the first 16 instances.

Acknowledgment

This research was funded by a Ph.D. grant of the Agency for Innovation by Science and Technology in Flanders (IWT).

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A robust optimization approach for scheduling surgeries in operating rooms

Inês Marques
Centre for Management Studies, Instituto Superior Técnico, Universidade de Lisboa
Centro de Matemática, Aplicações Fundamentais e Investigação Operacional,
Faculdade de Ciências, Universidade de Lisboa
e-mail: ines.marques@fc.ul.pt

M. Eugénia Captivo
Centro de Matemática, Aplicações Fundamentais e Investigação Operacional,
Faculdade de Ciências, Universidade de Lisboa
e-mail: mecaptivo@fc.ul.pt

1 Introduction

Uncertainty concerning the duration of a surgery is a major problem for the operating room planning and scheduling. Overestimating surgery durations may lead to underutilization of the surgical suite while an underestimation of the surgery durations increase the risk of cancellation of surgeries and incurs in extra work for the staff of the surgical suite. Underutilization of the surgical suite should be avoided since it represents a great inefficiency of a very expensive service and it contributes to increase the social problem of large waiting lists in the health care sector. In the literature, the surgeries duration is often treated as a deterministic parameter, which can be disruptive to the surgical schedule obtained by a mathematical model or a heuristic approach.

2 The problem

This work analyses the surgical case assignment problem in a general Portuguese hospital. Two type of decisions are taken: (1) to specify, from a long waiting list, the patients to be scheduled in a weekly planning horizon; and (2) to assign a day, an operating room, and a time block to the selected patients. Deterministic mixed integer programming models were previously developed in order to consider different perspectives of the multiple stakeholders of the surgical suite: the administration's version privileges equity and timely surgical access; the surgeons' version approximates the hospital's current practice; a mixed version models an intermediate strategy.

3 The robust approach

Simulations developed over the surgical schedules obtained considering average values for the surgeries' duration (deterministic approach) showed overbooked solutions: the hospital could expect an average time block occupation rate (with cleaning time) above 100% in the majority of the cases, and between 34% and 60% of the time blocks working in overtime, which would result in the cancellation of an excessive number of surgeries. This shows that deterministic solutions can be disruptive to a smooth running of the surgical suite, and a robust approach is desired.

Robust optimization models are used to handle the uncertainty in the duration of the surgeries, in order to keep the surgical schedules feasible regarding the operating room capacity constraints and also the surgeons' operating time limit. The robust approach tackles the uncertain surgeries' duration without the need to assume a given distribution for these random parameters, and allows to control the level of conservatism in the solutions. In this flexible approach, the surgical planner of the hospital (decision maker) can define the level of robustness and conservatism of the surgical schedules by selecting a budget of uncertainty. In addition, this approach allows to consider uncertainty in the constraints' coefficients by solving a problem from the same class as the deterministic version (mixed integer linear programming models) with added variables and constraints.

4 Computational experiments

Results of computational experiences using real data from the hospital under study (with 4,574 to 6,395 elective surgeries) will be presented and discussed. The schedules obtained are analyzed regarding quality and robustness, and are also compared with the surgical schedules performed by the hospital. The robustness of the solutions with respect to changes in the real surgery duration regarding the estimated duration is also studied. The performance of the surgical suite (in terms of the number of surgeries scheduled and the average time block occupation rate) decreases with higher budgets of uncertainty (reflecting a higher level of robustness and conservatism of the solutions) but ensuring a smoother running of the surgical suite. A trade-off between the performance of the surgical suite and the robustness of the solutions can be easily leveled by this robust approach.

Finding better health care decisions is a contribution of this collaborative work with the hospital.

Cost flow modeling for military manpower management

O. Mazari Abdessameud
Royal Military Academy, Departement of Mathematics
e-mail : Oussama.Mazari-Abdessameu@mil.be

F. Van Utterbeeck
Royal Military Academy, Departement of Mathematics

M. A. Guerry
Vrije Universiteit Brussel, Faculty of Economic and Social Sciences & Solvay Business School

Military manpower planning aims to provide the optimal required workforce with the adequate competences and ranks to fill the military job positions needed to accomplish the missions of the organization. The specificity of this organization is the hierarchical structure which restricts the personnel movement and no lateral recruitments but only at the base, i.e. in the lowest rank of the organization. Military personnel movements are of two kinds, vertical involving advancement in rank called promotion, and horizontal causing change in job position known as mutation. Besides, each job position in the military organization requires some conditions, related to rank, competence, experience or other individual characteristics, to make a soldier eligible for the position.

In order to optimally manage military personnel and meet the organizations demand, two kinds of model are used : manpower planning for the long term time horizon, which we call statutory logic, and personnel assignment with short term time horizon goal, which we call competence logic.

Statutory logic targets long term planning. This means it deals with recruitment, retirement and promotion, which have long term impact on the organization. On the other hand, competence logics goal is the short term assignment of personnel through mutation to satisfy the needs of the military organization.

However, these two logics affect each other, in a sense that if the long term planning fluctuates, the assignment policy should adapt. Moreover, if the assignment does not meet the requirements, what are the changes to make on the long term policy ? The aim of our research is to find a way to combine both logics in the same model, which permits the simultaneous optimization for the two combined logics. This model gives detailed information about the workforce distribution in the coming years and it allows the human resources managers to better forecast results of their policies.

We model the military personnel movement as a flow graph. Each node represents a homogeneous group of personnel having the same characteristics and occupying job positions with the same requirements on a given year (the job positions can be in different geographic locations). The graph is presented by layers where every layer is the annual workforce distribution. Arcs between nodes of

different layers represent the possible manpower movements, including : recruitment, military rank promotion, mutation and retirement.

Linear programming is used to find the optimal flow from the first layer to the last one. The demand does not always match the available flow (manpower) thus the use of virtual source and sink nodes with high costs and infinite capacities to maintain the balance.

The obtained results show that the model is able to simulate human resources management policies on both long and short term. It shows the long term impact of recruitment, promotion and retirement policies on the manpower. Besides, it simulates the different assignment preferences and vacancies severities, which allows to express job position priorities in a case of personnel lack or inflation. The model combines both statutory logic and competence logic in order to get a workforce distribution prediction over the coming years. Moreover, based on the expressed preferences, it anticipates the optimal mutations to perform for every studied year.

The impact of class size on academic underachievement: an advanced Stochastic Frontier approach

Deni Mazrekaj
KU Leuven, Leuven Economics of Education Research
deni.mazrekaj@kuleuven.be

Kristof De Witte
KU Leuven, Leuven Economics of Education Research
kristof.dewitte@kuleuven.be
Maastricht University, Top Institute for Evidence Based Education Research
k.dewitte@maastrichtuniversity.nl

Thomas Triebs
ifo Institute - Leibniz Institute for Economic Research at the University of Munich
triebs@ifo.de

This paper proposes an alternative approach to measure underachievement and the influence of its drivers. In particular, we decompose the classical error term in the education production function using an advanced Stochastic Frontier Analysis (SFA) model by Lien, Kumbhakar, and Alem (2016). This allows us to separate persistent and time-varying underachievement from pupil heterogeneity and random noise. The results suggest that underachievement in Flemish elementary schools amounts, on average, to around 46%. This estimate is similar to the estimate of 49% by Peterson & Colangelo (1996), but grossly differs to other, more recent estimates which typically amount to about 10-30% (Education Council, 2007; Obergriesser & Stoeger, 2015; Preckel & Brunner, 2015). If an effective policy managed to remove underachievement entirely, the average mathematics test scores would rise by 63%. Furthermore, in contrast to the study by Peterson and Colangelo (1996) in which age is a major driver of underachievement, our results suggest that underachievement is mainly driven by permanent factors, making it likely to persist over time. Finally, the results provide support for the view that gifted pupils and male pupils are more prone to underachievement than their ungifted and female peers.

The second set of findings suggests that, from a threshold of 19 pupils onwards, larger classes exacerbate underachievement. The underlying mechanism for this observation can arise from the teacher time allocation between general lecturing and one-on-one time with the pupil (Bosworth & Caliendo, 2007). In larger classes, teachers are unable to provide individualised instruction to pupils, which is why they resort to more general lecturing. Moreover, larger classes

might have a larger variance in abilities (definitely in primary education where pupils are not tracked yet), which makes it more difficult for teachers to adopt the teaching style to the different ability levels of the pupils (Van Klaveren & De Witte, 2014). On the other hand, in classes with less than 19 pupils, larger classes may actually reduce underachievement. This suggests that in primary education, a class of 19 pupils is the most optimal size for avoiding underachievement.

Interestingly, once a distinction is made between gifted and ungifted pupils, the results indicate that larger classes decrease underachievement for the former, while increasing underachievement for the latter above a threshold of 17 pupils. This is in line with our presumed mechanism. Larger, and thus, more heterogeneous classes in terms of ability levels, may induce the teacher to differentiate his/her teaching style (Bosworth & Caliendo, 2007). More gifted pupils are likely to benefit from this differentiation as they are often independent workers. By contrast, ungifted pupils are likely to be more confused by the differentiated teaching style, explaining their rising underachievement. In smaller classes however, teachers may disproportionately allocate more time to ungifted pupils, reducing their underachievement. Brown and Saks (1987), and Betts and Shkolnik (1999) provide empirical support that teachers may favour low-ability pupils as they are likely to show higher improvement levels than high ability pupils. This would explain our conclusion that smaller classes where individualised instruction is possible reduce underachievement for ungifted pupils above a certain threshold, increase underachievement for gifted pupils, and reduce underachievement overall.

This paper delivers two interesting policy recommendations. On the one hand, while overall underachievement may be reduced by a drop in class size to the optimal level of 19 pupils, it seems imperative that task difficulty and performance expectations are individualised so that both gifted and ungifted pupils can perform to the best of their abilities. Once this has been accomplished, the reduction in class size can achieve its objectives. If not, class size reduction may have unintended consequences and may actually exacerbate underachievement for gifted pupils.

Moreover, it is important to tackle the effect of gender on underachievement. Consistent with the earlier literature (McCall, 1994; McCoach, 2002; Peterson & Colangelo, 1996) and contrary to more recent estimates (Preckel & Brunner, 2015), our results indicate that boys are much more likely to underachieve than girls. However, the ratio of male to female underachievers who seek professional assistance is one to five (Mandel & Marcus, 1995). This may be mainly because parents are more likely to think they have a lazy and unmotivated son than that they have a lazy and unmotivated daughter. It is thus important to inform parents about underachievement, so professional guidance can be offered to both boys as girls.

CIPS: a new method to handle robustness in the Job Shop Scheduling problem

Beatriz M. Méndez-Hernández, Yailen Martínez-Jiménez
Universidad Central "Marta Abreu" de Las Villas, Department of Computer Science
e-mail: bmendez@uclv.edu.cu, yailenm@uclv.edu.cu

Erick D. Rodríguez-Bazan
International Centre for Theoretical Physics
e-mail: erodra_g@ictp.it

Pieter Libin, Ann Nowé
Vrije Universiteit Brussel, CoMo Lab
e-mail: pieter.libin@vub.ac.be, ann.nowe@vub.ac.be

Many scheduling systems designed to optimize manufacturing processes are presented in the literature from a theoretical point of view and assume a deterministic environment to execute the schedule. However, real world scheduling problems operate in dynamic environments and can be prone to unforeseen circuntances (e.g. machine breakdowns, operations that take longer to execute than expected or the unavailability of resources). Job Shop is one of the more complex (i. e. NP-hard [1]) scheduling problems. This problem consists of a set of jobs and machines, where each job includes different operations that have to be processed by the set of machines in a predetermined order. New methods that aun to solve the Job Shop scheduling problem typically focus on improving the makespan (i. e. schedule completion time) in deterministic environments. However, for real-world scheduling problems, it is equally important to be able to recover from unexpected events. Robust schedules can be constructed in a proactive or reactive fashion. Proactive schedules are created by adding sack where it is deemed necessary. Reactive schedules, on the other hand, are dynamic and modify the execution pathway of the schedule to absorb potential disturbances.

We propose an approach based on the concept of criticality, CIPS (Critical Interval Proactive scheduling), to build proactive robust schedules aimed at solving Job Shop scheduling problems. We identify critical intervals per machine, an interval is critical if the number of consecutively executed operations greater than a threshold defined by the user. Our new technique only considers the machine breakdowns, we assume the processing times of the operations are known. When our algorithm detects a critical interval, a predefined slack is added according to the processing time of the consecutive operations and the schedule horizon (i. e. the end time of the operation) assuming that the probability of failure increases as the schedule horizon advances [2]. The added slack is defined as: $dur_{oper} * \frac{t}{sum_{pt}(M)}$, where dur_{oper} is the sum of the processing times of the consecutive operations, t is the end time of the last operation and $sum_{pt}(M)$ is the

sum of processing times of the all operations to executed on machine M.

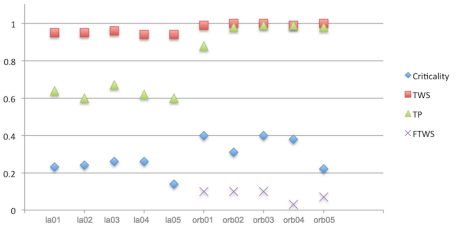
The algorithm performance was evaluated in a simulated setting. The implemented method has been compared to other three techniques: Temporal Protection (PT), Time Window Slack (TWS) and Focused Time Window Slack (FTWS) [2]. To measure a technique's robustness we considered the capacity to absorb the disturbances by computing the deviation between the real and expected makespan. The approaches were evaluated on 10 OR-library benchmarks problems and for each instance 50 disturbances ware sampled from a Poisson distribution.

Figure 1a shows the makespan of the robust schedules obtained applying the four techniques (Column CIPS, TP, TWS, FTWS) and by simulating the schedule with disturbances (column Real MS). Figure 1b shows a plot with the deviation between the real and the expected makespan. FTWS is not included in figure 1b because this technique was unable to absorb the disturbances that were modelled for the first 5 instances.

Our new technique shows less deviation for the instances 5x5 (machines x jobs). However when the instances grow (i.e. the number of machines or/and the number of jobs increase), the FTWS is able to absorb the disturbances and its deviation is better compared to the other techniques.

Inst	CIPS	TP	TWS	FTWS	Real MS
la01	907	2258	16046	740	824
la02	1151	2188	16517	762	880
la03	1033	2331	17461	748	762
la04	1025	2028	13595	685	761
la05	856	1856	12788	653	738
orb01	2275	11432	137175	1529	1369
orb02	1617	45069	432337	1239	1109
orb03	2209	96979	968164	1476	1317
orb04	2038	111160	174366	1296	1259
orb05	1437	59108	598008	1207	1127

(a) Results for the makespan of the robust schedules



(b) Results of the deviation between real and expected makespan

Figure 1: Results of CIPS, TP, TWS, FTWS for 10 instances of the benchmark

Our experiments demonstrate that our approach is able to absorb all disturbances with a similar behaviour regardless of the instance size. FTWS works better when the instance size is large because this technique takes into account the schedule horizon. As our results show, TWS is too conservative with respect to assigning slack to operations which results in unnecessarily pessimistic schedule duration predictions.

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Scheduling procedures minimizing the total user ride time in dial-a-ride problems

Yves Molenbruch[1,2], Kris Braekers[1,2], An Caris[1]
[1] Hasselt University, Research Group Logistics
[2] Research Foundation Flanders (FWO)
e-mail: yves.molenbruch@uhasselt.be

A dial-a-ride system is an application of demand-dependent, collective people transportation [2]. Each user requests a trip between an origin and a destination of choice. A time window is imposed on either the departure or the arrival of the user and his ride time (the time spent in the vehicle) is bounded. The service provider attempts to develop efficient vehicle routes and time schedules, respecting these service constraints and the technical constraints of any pickup and delivery problem (PDP) [3]. A frequent objective is to minimize operational costs subject to full demand satisfaction, but service level criteria may be optimized as well. Balancing the human and economic perspectives involved in solving such a dial-a-ride problem (DARP) is essential for organizing quality-oriented, yet efficient transportation of users with special needs, such as door-to-door transportation for elderly and disabled.

Solution algorithms need to invoke a scheduling procedure to assess the time feasibility of a route, meaning that the start of service in each node needs to satisfy time-related constraints (time windows, maximum user ride time and maximum route duration). Due to the presence of the maximum user ride time constraint, scheduling is more complicated for the DARP than for a PDPTW [2]. The most common scheduling heuristic in the literature, designed by Cordeau and Laporte [1], first computes the earliest schedule respecting time windows and travel times, after which the forward time slack principle eliminates potential ride time or route duration violations whenever possible. Since this procedure does not consider service quality, Parragh et al. [4] modified the forward time slack computation such that the total user ride time is minimized at the expense of occasional incorrect infeasibility declarations. The present work introduces a new scheduling heuristic that minimizes the total user ride time according to a different strategy. Starting from a schedule with minimal ride times for the given time windows, potential travel time shortages are eliminated while keeping ride time increases as limited as possible. Besides, a variant imposing additional real-life constraints on the allocation of waiting time is presented.

Extensive computational tests on different sets of benchmark data show that the proposed procedure is fast and fails on fewer routes than Parragh et al. [4]. In addition, feasible schedules exhibit smaller deviations from the optimal solution. A sensitivity analysis is performed to analyze the impact of service constraint vari-

ations on the percentage of incorrect infeasibility declarations. Finally, imposing additional waiting constraints turns out to considerably impact the feasibility of solutions.

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Acknowledgements

This work is supported by the Interuniversity Attraction Poles Programme, initiated by the Belgian Science Policy Office. (Research Project COMEX - Combinatorial Optimization: Metaheuristics & Exact Methods)

An integrated approach for order picking and vehicle routing in a B2C e-commerce context

Stef Moons, Katrien Ramaekers, An Caris
Hasselt University, Research Group Logistics
e-mail: {stef.moons,katrien.ramaekers,an.caris}@uhasselt.be

Yasemin Arda
HEC Management School, University of Liège, QuantOM
e-mail: yasemin.arda@ulg.ac.be

Every year, business-to-consumer (B2C) e-commerce sales increase. In the last decade, the B2C e-commerce sales has been growing annually with 12% on average in Europe. More specific, in 2015, the European B2C e-commerce sales grew with approximately 13.5% [1]. New challenges and opportunities for the logistic system are created by the rise of e-commerce [3]. New distribution channels and structures arise, which lead to more complex distribution networks. Moreover, customers order more frequently in smaller quantities in an e-commerce context. As a consequence, the number of consignments increases, which makes the consolidation for delivery more complicated. Customers still expect a fast and accurate delivery. In order to fulfill these high customers' expectations all supply chain functions have to be optimized simultaneously.

However, nowadays, in most e-commerce DCs a fixed cut-off time is implied before which all orders need to be picked. This cut-off time separates the warehouse operations and delivery operations. By integrating both problems, the cut-off time can be eliminated and late orders can be handled with more flexibility. Instead of solving an order picking (OP) problem and a vehicle routing problem (VRP) separately and sequentially, these two problems can be integrated into a single optimization problem. Both an order picking schedule and vehicle routes need to be determined. According to the authors, it is the first time order picking and vehicle routing decisions are integrated. In literature, papers on coordinating supply chain functions generally integrate a production environment with a VRP [2]. A mathematical formulation for an integrated order picking-vehicle routing problem (OP-VRP) in a B2C e-commerce context is presented. The performance of the proposed integrated OP-VRP is compared to an uncoordinated approach in which first an order picking problem is solved and afterwards a VRP. The total costs obtained by using an uncoordinated approach are compared to the these obtained by using the integrated approach.

In the DC, manual order pickers travel along the different picking locations in a single picking zone, i.e., a picker-to-product system [4]. The DC employs a fixed number of regular order pickers. Additional order pickers from a fixed pool of flexible workers can be hired in case of high customer demand. However, a maximum number of order pickers is allowed to work in parallel to avoid conges-

tion in the picking aisles. Per time unit an order picker works a wage is incurred. The wage of an additional hired picker is higher. Each order, which can consist of one or more order lines, is picked individually without interruption in a single tour through the warehouse, i.e., single order picking policy. Thus, batching of orders is not allowed. The delivery operations are executed by a limited number of vehicles. Both a variable cost incurred per time unit of the tour length, which includes the driver's wage and the fuel cost, and a fixed cost for using a vehicle are incurred. Service times at the warehouse and the customers are taken into account.

Experiments with small-size instances with up to 20 customer orders are executed. The integrated approach always results in a better solution compared to the uncoordinated approach. Integration of both problems leads to cost savings of 12% on average, with even up to approximately 30%. Integration lowers the need to hire additional order pickers. Due to the higher flexibility of the arrival times of the vehicles at the DC, vehicles do not have to wait before their delivery route can start, which results in lower driver wages. Furthermore, when order picking and vehicle routing decisions are integrated into a single problem, B2C e-commerce companies can offer a higher service level to their customers. Companies can allow their customers to place their orders later and still offer the same delivery time windows as with an earlier placed order. In the uncoordinated approach, it is not possible to offer this service, because all orders need to be picked before the cut-off time, and when orders are placed late, not enough time is left to pick all these orders on time. The integrated problem can be solved within one minute on average for instance classes with 10 and 15 customer orders. Solving the instances with 20 customer orders can take up to 17 hours. As a real-world distribution center has to handle a large number of orders a day, a heuristic needs to be developed to solve the integrated order picking-vehicle routing problem in a small amount of time.

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This work is supported by the Interuniversity Attraction Poles Programme initiated by the Belgian Science Policy Office (research project COMEX, Combinatorial Optimization: Metaheuristics & Exact Methods).

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A new approach to scheduling home care personnel in Flanders

Federico Mosquera Pieter Smet
Greet Vanden Berghe

KU Leuven, Department of Computer Science CODeS & imec-ITEC
Gebroeders De Smetstraat 1, 9000 Gent, Belgium
e-mail: federico.mosquera@cs.kuleuven.be

As the size of the elderly population continues to grow, so does the demand for home care services in Flanders. In order for home care organizations to deal with the increased pressure to deliver the required services, new decision support models are necessary which can handle the ever-increasing problem complexity. Home care scheduling, as considered in the academic literature, involves the scheduling, assignment and routing of caregivers in order to fulfill clients' demands, represented by various tasks that must be performed at different geographic locations, that is, the clients' houses [1]. Solutions for this optimization problem are evaluated based on several criteria such as total distance traveled, caregiver idle time, client satisfaction rate, the occurrence of unscheduled tasks and various other task-related objectives.

Current practice in the considered Flemish home care organizations includes assigning four-hour blocks of service to either a morning or afternoon slot, without taking into account the clients' specific task needs. By ignoring detailed information concerning which tasks must be carried out at a client's home, rigid schedules are constructed. To address this issue, the present study introduces a rich, general model for home care scheduling which considers client and caregiver characteristics occurring in practice. By acknowledging this additional data, the proposed approach enables greater flexibility allowing the scheduling of detailed tasks, which themselves then constitute flexible blocks to be performed at a client's home.

An important feature of the proposed model is the presence of flexible tasks, both in terms of duration and frequency. As an example of flexible task duration, consider the task of preparing a meal for a client, which may take any time ranging from half an hour to two hours. If, due to a lack of time, this task cannot be scheduled for the full two hours, the client's meal should be prepared faster, thereby resulting in a penalty for this part of the solution. Moreover, the number of times this task is performed is also subject to a degree of flexibility. For example, it may be agreed upon that cooking will be done five times per week. Depending on the number of available caregivers, the actual number of visits may be dropped to an agreed upon minimum, for example three times per week. However, doing so will again result in a penalty.

Data obtained from home care organizations will be used to demonstrate the impact of the new modeling approach. Computational results will be presented at the conference.

Acknowledgments: This research was carried out within the HACES project, Human-Centred Scheduling for Improved Home Care. The HACES project is part of the imec.icon Cooperative Research Program. Editorial consultation provided by Luke Connolly (KU Leuven).

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Automatic design of Hybrid Stochastic Local search algorithms

F. Pagnozzi
Université Libre de Bruxelles, IRIDIA
e-mail: federico.pagnozzi@ulb.ac.be

Stochastic local search [4], SLS, methods such as Iterated Local Search (ILS), Iterated Greedy (IG), Tabu Search (TS), GRASP or Simulated Annealing (SA) have been used with good results for many NP-hard optimization problems. Typically, when tackling a problem, an algorithm designer has to decide which one of these methods to apply and how to adapt the chosen metaheuristic to the problem. The concept of automatic algorithm design can be traced back to the introduction of automatic configuration tools, such as ParamILS [6], SMAC [5] and irace [10], and unified algorithm implementations such as MOACO [11], UACOR [9], SATenstein [8]. The former simplifies the configuration of algorithms with big parameter set, while, the latter expose the design choices, when building a SLS, as parameters. By using the two together, we can automatize the design of specific SLS in a process called programming by optimization [3]. Here we propose a way how to adapt these ideas towards generating high-performing algorithms for important scheduling problems. Our method is based on decomposing the SLS algorithms to simple components and to define a set of rules to describe how to combine them. Finally, we use an automatic configuration tool to find the best combination of components that satisfies the given rules. The presented system can choose either to instantiate an exisisting SLS method or to create a new one by hybridizing two, or more, SLS algorithms. More specifically, we use irace as automatic configuration tool, expressing the rules using the grammar approach presented in [12], and a new framework, EMILI to implement the components and to instantiate the algorithms.

EMILI has been designed to be an unified framework for the automatic SLS design. Its architecture is based on a general definition of the components of a SLS so that the algorithms are not linked to any particular problem definition. To test our approach we tackle the Permutation Flowshop Problem (PFSP). This problem has been extensively studied since it was formally described [7] and it has been proved to be $\mathcal{NP}$-hard for various objective functions [7] [2] [1]. Moreover, PFSP has a very simple structure that can be used to represent many other permutation and flowshop problems. This flexibility and the presence of many high performing SLS algorithms make PFSP a very good test case for our method. In particular, in this talk we generate algorithms to solve three of the most studied PFSP objectives: the minimization of the makespan; the minimization of the sum of completion times, and the minimization of the total tardiness. We compare the generated algorithms with the state of the art for each objective. Our results show that the generated algorithms outperforms the

state of the art for every objective.

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Impact of joint purchasing on the competition among group members in the downstream market with incomplete information

Wenli Peng
Université catholique de Louvain, CORE
e-mail: wenli.peng@uclouvain.be

Philippe Chevalier
Université catholique de Louvain, CORE
e-mail: philippe.chevalier@uclouvain.be

Gilles Merckx
Université de Namur, Department of Business Administration
e-mail: gilles.merckx@unamur.be

Aadhaar Chaturvedi
Université de Namur, Department of Business Administration
e-mail: aadhaar.chaturvedi@unamur.be

1 Abstract

Joint purchasing is a procurement strategy adopted by supply chain members to reduce procurement cost (both fixed cost and variable cost) and secure the supply. Purchasing consortia among non direct competitors are well established in industries such as restaurants and hotels, healthcare, cable television franchises, etc ([1], [2]). Buying alliances can also be formed among competitors, well documented evidences include apparel manufacturers grouping orders for high quality yarn ([1]), supermarket rivals in the UK pooling volumes of own label products ([3]), Chinese main television manufacturers placing group orders with display panel suppliers during 2009 and 2010, etc. Our paper studies the impact of joint purchasing in the competitive environment. On the one hand, buyers obtain lower purchasing prices through demand aggregation. On the other hand, they also reveal private demand information, which would have a dampening effect on market competitiveness. In this paper, we aim to address the following research questions: what is the impact of demand variability on the formation of coalitions? what is the impact of information asymmetry on the formation of coalitions? Under what conditions is individual purchasing (group buying) preferable to group buying (individual purchasing)?

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A mathematical model and a meta-heuristic for the Cast Batching Problem

N.-H. Quttineh
Linköping University, Departement of Mathematics
e-mail : nils-hassan.quttineh@liu.se

We present the challenges of planning the order-driven continuous casting production at the Swedish steel producer SSAB. Customers place orders for end products, which is translated into a demand of slabs of a certain steel grade and with given order-specific restrictions on weight, length and breadth. The overall planning problem is to minimize production waste while fulfilling the order-based demand, and we decomposed the problem by firstly schedule and group orders by steel grade, and secondly decide in which sequence the scheduled orders for each day should be cast.

This talk will focus on the second part, the Cast Batching Problem (CBP), where the objective is to minimize production waste which unavoidably occurs as orders of different steelgrades are cast in sequence. The waste is due to so called mixing zones, and simply speaking, some groups mix better than others. The ultimate goal is to develop a decision support tool which could facilitate the daily work situation for the planners at SSAB.

The Cast Batching Problem

In the Cast Batching Problem, a given set of groups must be scheduled into a limited number of tundishes so that the production waste is minimized. Each group consists of orders that belong to the same steelgrade, and the problem is to sequence the groups into tundishes. Each tundish can only handle a limited amount of orders, and the waste depends on the transition between the steelgrades within a tundish.

Further, there are restrictions on compatibility between groups, meaning that not all groups can be sequenced within the same tundish. To complicate things even more, the width of the orders in each group will also contribute to the production waste. If two groups are sequenced after each other, and they include orders of different widths, waste is unavoidable since casting is a continuous process.

To summarize, given a list of groups to cast a certain day, and a set of available tundishes, this is the problem we want to solve :

- Decide which groups to put together in a tundish.
- Decide a casting sequence for the groups within each tundish.
- The objective is to minimize **waste**.

Mathematical model

A mathematical model for the cast batching problem at SSAB exists, and it has been applied to several problem instances based on real data. The model contains many binary variables and it is time-consuming even for state-of-the-art solvers like cplex to find optimal solutions. This indicates that the model at hand is weak, and different ways to strengthen it is a topic for further research.

Meta-Heuristic

Due to the weak model, it is difficult to prove optimality even for moderate sized problem instances, and hence we have explored the possibility to apply a meta-heuristic. A Tabu-search procedure has been implemented, where certain problem characteristics are exploited, and the meta-heuristic is able to find near-optimal solutions within reasonable time frames.

Sequential testing of n-out-of-n systems : A comparison of exact approaches

Salim Rostami
Management Department, IESEG School of Management, Lille, France
ORSTAT, Faculty of Economics and Business, KU Leuven, Belgium
e-mail : salim.rostami@kuleuven.be

Stefan Creemers
Management Department, IESEG School of Management, Lille, France
Research Centre for Operations Management, KU Leuven, Belgium

Roel Leus
ORSTAT, Faculty of Economics and Business, KU Leuven, Belgium

The goal of sequential testing is to discover the state of a system by testing its components one by one. We consider n-out-of-n systems, which function only if all the n components work. The testing continues until the system state is identified. The tests have known execution costs and failure probabilities and may be subject to precedence constraints. The objective is to find a sequence of tests that minimizes the total expected cost of the diagnosis.

We propose a linear formulation for the foregoing problem, which could also be applied to some other similar sequencing and scheduling problems. We show that this formulation is a Dantzig–Wolfe decomposition of a compact nonlinear formulation of the problem. Moreover, a branch-and-price and a dynamic-programming (DP) algorithm are proposed for solving the problem. Our computational results show that DP outperforms state-of-the-art algorithms. We empirically show that DP significantly increases (up to 50%) the size of the instances that can be solved to optimality under practical memory and CPU-time limits.

The assembly line feeding problem: classification and literature review

Nico André Schmid
Ghent University, Department Business Informatics and Operations Management
e-mail: nico.schmid@ugent.be

Veronique Limère
Ghent University, Department Business Informatics and Operations Management
e-mail: veronique.limere@ugent.be

In recent years some trends in several product assembly systems emerged, namely mass-customization [Boysen et al., 2007], integration of new product functionalities [Göpfert et al., 2016] and increase in the number of models (e.g. BMW, a German car manufacturer, increased the average number of models offered per year to 37.85 in the period between 2010 and 2016, compared to only 22.3 in the period between 2000 and 2010). These trends have a significant impact on assembly systems since all of them lead to an increasing number of parts required for the final assembly, either by increasing the number of parts required at the border of line (BOL) in general (for new functionalities or new models) or by increasing the number of part variants (mass-customization).

Within the assembly line feeding problem (ALFP), the optimal way of supplying assembly stations with parts is examined by assigning different feeding policies to parts. This is mostly based on cost minimizing considerations. The most prevalent line feeding policies are *line stocking*, *kanban*, *sequencing* and *kitting* [Limere et al., 2015, Sali and Sahin, 2016]. Line stocking and kanban both provide parts in homogeneous filled load carriers. Applying line stocking, a full load carrier (as supplied by the supplier) is provided to the BOL, whereas applying kanban means providing smaller quantities by splitting load carriers into bins. In sequencing and kitting, parts are prepared in the order of demand. In case of sequencing, a container holds variants of one particular component, whereas in case of kitting, different components are grouped and load carriers are filled heterogeneously.

The focus of this research is on reviewing literature about the actual ALFP, namely on the assignment of line feeding policies to parts, as well as about related subproblems like e.g. the optimization of milkrun transports within assembly systems. This problem is highly complex due to different decision levels, processes, variable parameters and constraints. In order to help structuring previous and future work, we provide a classification with a three tuple notation as firstly introduced by Graham et al. for machine scheduling [Graham et al., 1979]. Significant decisions and subproblems, occuring in different processes within the ALFP, are classified. This problem includes only in-house logistics and can hence be delimited from external logistics or SCM. Research in this field is becoming more

and more attractive to researchers, which can be seen by the rising number of publications. Research is mainly initiated in 1992 [Bozer and McGinnis, 1992] and round about 100 papers are analyzed in this review.

The main contribution of this work is twofold. First, we do not only summarize previous research topics but also indicate open research fields, which hopefully motivates researchers to fill the research gaps. Secondly, this work provides, through the classification, a comprehensive framework for researchers to easily identify decisions and subproblems of the ALFP, which can be included in future work.

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Two-stage supply chain design with safety stock placement decisions

Matias Schuster
Université catholique de Louvain, Louvain School of Management
e-mail: matias.schuster@uclouvain.be

Stefan Minner
Technische Universität München, TUM School of Management
e-mail: stefan.minner@tum.de

Jean-Sébastien Tancrez
Université catholique de Louvain, Louvain School of Management
e-mail: js.tancrez@uclouvain.be

Supply chain management provides an effective way to increase competitive advantage by reducing operational costs and improving customer's satisfaction. A critical decision that impacts the performance of a company in the long term is the strategic design of its supply chain. Facilities are a key driver of supply chain performance in terms of responsiveness and efficiency. On the one hand, companies can gain economies of scale when centralizing products in one location, which leads to an increase in efficiency. On the other hand, this efficiency increase comes at the expense of responsiveness, as many of the customers may be located far from the facilities [1]. Moreover, in today's volatile economy, demand uncertainty is a major concern for companies, and it forces them to hold safety stocks. Therefore, the optimal placement of safety stocks is an important decision when designing the supply chain as it has a direct impact on the service quality. The decisions on where to locate facilities and where to place the safety stocks in these facilities are interdependent by nature. In this context, the integration of these decisions leads to a more efficient design of the supply chain. In this paper, we propose a supply chain design model that integrates facility location with safety stock placement and delivery strategy decisions, to reflect their interdependence and ultimately improve the resulting supply chain design. We consider two-layer supply chains composed of retailers, distribution centres (DCs) and one central plant. The mathematical model simultaneously determines: *(i)* the number and location of opened DCs, *(ii)* the allocation of flows between DCs and retailers, *(iii)* for which retailers the opened DCs hold safety stocks, and *(iv)* the delivery time options at retailers. Our model minimizes the costs of transportation, facility opening, cycle inventory, ordering and safety stocks. The resulting non-linear model is formulated as a conic quadratic mixed-integer program that can be solved to optimality in reasonable computational time using standard optimization software packages.

The safety stock placement decisions are modelled using the guaranteed-

service approach. By considering the extreme point property [2], we avoid the use of continuous service time variables between DCs and the retailers, and instead use binary variables that explicitly decide for which connected retailers the opened DCs hold safety stocks. Several trade-offs are captured by integrating safety stock placement decisions into the strategic supply chain design problem. On the one hand, when safety stocks are only held at retailers, the company can benefit from the lead time pooling effect in certain situations (e.g., for long lead times between DCs and the retailers, and short order lead times between the central plant and the DCs). On the other hand, when safety stocks are held at DCs, the company can reduce safety stock costs by pooling demand variability at DCs [3]. Therefore, interesting managerial insights arise from the balance between lead time and demand variability pooling strategies, which are influenced by the number of opened DCs, the safety stock placement and the delivery strategies.

We also consider two customer classes that differ with respect to their delivery time preferences at the retailers, differentiating between express and regular delivery customers. Regular customers at retailers are served with a given service time. To improve its responsiveness, the company also offers express deliveries for those customers that request to be served immediately and accept to pay an extra fee. The income originated by the extra fee of express deliveries will balance the safety stock cost increase caused by the improvement of the delivery time. Interesting managerial insights are revealed when we consider different customer classes in a supply chain design model. The trade-offs arise from the selection of express and regular deliveries, which are dependant on the lead times, the express deliveries demand, the service times and the fees. In particular, when considering short lead times between DCs and the retailers, express deliveries are offered more often as safety stock costs are limited.

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A column generation approach for the graph b-Coloring Problem

Fabio Sciamannini
Université libre de Bruxelles, Département d'Informatique
e-mail : fabio.sciamannini@ulb.ac.be

We present a branch-and-price framework for solving the b-Coloring Problem, i.e. a Vertex Coloring Problem where each subset of vertices receiving the same color contains at least one node, the dominating node, adjacent to every other color used. We suggest an approach based on an integer programming formulation of the b-coloring. This formulation, called independent set formulation, involves an exponential number of variables. In order to deal with them, we show that is possible to solve the problem via column generation, where variables are dynamically introduced into the model by iteratively solving a pricing problem. Although requiring the solution of a difficult subproblem as well as needing sophisticated branching rules, this approach based on a Dantzig-Wolfe decomposition scheme, provides tighter LP relaxation and eliminates the symmetry that usually affects the formulation of the b-coloring. Despite the importance of the problem, to date, there exist in literature no contributions concerning exact methods exploiting a column generation paradigm embedded in a Branch-and-Bound scheme (i.e. a Branch-and-Price algorithm) to solve the b-Coloring problem. We show that such approach appears efficient to solve moderate to big scale instances and it turns out to be useful for obtaining good lower bounds that can be used to speed up the exact methods existing. Some implementation details and initial computational experience are presented.

A local search approach to the many-to-many carpooling problem

Pieter Smet
KU Leuven, Department of Computer Science CODeS & imec-ITEC
e-mail: pieter.smet@cs.kuleuven.be

By reducing the number of cars on the road, carpooling presents an effective approach for addressing traffic congestion. Moreover, carpooling has several beneficial side-effects such as reducing vehicle emissions, fuel savings, reducing the number of required parking spaces and decreasing the number of accidents on roads [1]. Several initiatives aim to facilitate and automate carpooling organization. Typically, users register as drivers or passengers and the system subsequently groups these users into appropriate carpools and constructs the drivers' routes. These two decisions define a complex combinatorial optimization problem which has received some attention within operations research literature. However, due to the scale of this integrated optimization problem, academic research has been mostly focused on solving the subproblems independently. The present study introduces a local search approach capable of simultaneously addressing the two aforementioned problems in optimizing the carpooling process. Moreover, in contrast to other models, the present study considers the many-to-many problem variant, in which users may have different origins and different destinations.

Each user is characterized by a home location, a destination, an earliest departure time and a latest arrival time. Moreover, it is specified whether users have a car or not, the car's capacity and whether the user is willing to act as a passenger. The goal is to generate a set of carpooling routes, defined as paths beginning from the driver's home and ending at their destination. Other users may be picked up and dropped off along these paths so long as capacity and time window constraints are respected. Users are permitted to walk to another user's home to be picked up there, provided the time required to walk to this alternative pickup location does not exceed the user's maximum walking time. Similarly, users may be dropped off at another user's destination to then walk to their true destination. If, due to time and capacity restrictions, a user cannot be assigned to any route, a large penalty is incurred. In practice, unassigned users get to their destination by public transport.

A local search approach is used to generate solutions for the proposed model. First, an initial solution is constructed by a first fit heuristic, which is subsequently improved by a local search algorithm using several neighborhoods. The first set of neighborhoods modifies routes by only considering currently assigned users. This is achieved by moving and swapping users between routes and changing the order of stops within a single route. The second set of neighborhoods modifies the current solution by adding unassigned users or removing currently assigned users. A compound move in which an assigned user is replaced by an

unassigned user is also considered. The final set of neighborhoods enables users to be pickup up or dropped off at alternative locations.

A series of computational experiments demonstrates the performance of this local search approach on real data provided by an industry partner. The results provide an estimation of the benefits attainable by simultaneously optimizing various carpooling decisions.

Acknowledgments: This research was supported by the Belgian Science Policy Office (BELSPO) in the Interuniversity Attraction Pole COMEX (http://comex.ulb.ac.be). Editorial consultation provided by Luke Connolly (KU Leuven).

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Testing Random Utility Models: An optimization problem

B. Smeulders
Université de Liège, HEC, QUANTOM
e-mail: bart.smeulders@ulg.ac.be

Abstract

Random Utility Models are often used in Economics, either to explain changing choice or to model preference at the level of a population of decision makers. However, testing whether observed choices are consistent with a RUM can be a difficult task. We look at a computational challenge encountered in a recent paper by Kitamura and Stoye [1] and look at two formulations to tackle this problem.

1 Preliminaries

We consider a set of n different choice situations T. In each choice situation t, there is a set of m_t choice alternatives A_t, indexed by i. We use $a_{t,i}$ to denote individual choice alternatives. Choice alternatives can be dominated by other choice alternatives, i.e., any rational decision maker must prefer the dominant alternative over a dominated alternative, we write $a_{t,i} \succ a_{s,j}$. Let $P = \{\bar{a}_t \,|\forall t \in T\}$ be a preference profile, with $\bar{a}_t \in A_t$ being the most preferred alternative in the set A_t.

Definition 1. *A preference profiles $S = \{\bar{a}_t \,|\forall t \in T\}$ is consistent with rational choice if and only if there does not exist a sequence of choice situations $1, \ldots, i$ such that:*

$$\bar{a}_1 \succ \ldots \succ \bar{a}_i \succ \bar{a}_1. \tag{1}$$

We now turn to Random Utility Models. Suppose we observe choices from a population of decision makers, we obtain the dataset $R = \{r_{t,i} \,|\forall t \in T, i \in A_t\}$. $r_{t,i}$ is the rate at which alternative $a_{t,i}$ is chosen from the set A_t ($\sum_{i \in A_t} r_{t,i} = 1$). The question is now whether the observed rates of choice in the population can be explained, or by rational decision makers. To this end we define the set O, the set of all preference profiles consistent with rational choice. We furthermore define $O_{t,i}$, the set of all preference profiles consistent with rational choice, for which $\bar{a}_t = a_{t,i}$.

Definition 2. *A dataset R is rationalizable by a RUM of rational preference profiles if and only if there exist numbers $x_m \geq 0, \forall m \in O$ for which:*

$$\sum_{m \in O_{t,i}} x_m = r_{t,i}, \qquad \forall t \in T, \forall i \in A_t. \tag{2}$$

2 The Problem

By the very nature of RUM, it is likely that observed choices are not rationalizable according to Definition 2, even if the underlying preferences are consistent with the model. Due to the finite number of observations, the observed rate of choice for any given choice situation is unlikely to reflect the actual preferences of the population. The question is thus not whether there exist numbers x_m such that Equalitiy (2) holds, but whether the deviation is sufficiently small that it can be explained by randomness in the observed choices. Kitamura and Stoye [1] develop a statistical test, based on the Euclidean distance between r and the polytope formed by the different rational preference profiles. We use P_{RU} to denote this polytope. This test requires solving either of the following problems.

$$\text{Minimize} \qquad \sum_{i,j \in A} d_{t,i}^2 \tag{3}$$

$$\sum_{m \in O_{t,i}} x_m + d_{ij} = r_{t,i}, \qquad \forall t \in T, \forall i \in A_t. \tag{4}$$

$$x_m \geq 0, \qquad \forall m \in O. \tag{5}$$

$$\text{Minimize} \qquad \sum_{i,j \in A} (r_{t,i} - y_{t,i})^2 \tag{6}$$

$$y_{t,i} \in P_{RU}. \tag{7}$$

However, neither are straightforward. The number of rational preference profiles may already be exponential in the number of choice situations and alternatives. Likewise, no description of P_{RU} is available, and it depends on the choice situations, alternatives and dominance relationships. In this talk, we will look at these problems and explore some possible approaches to solving them.

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Integer programming based heuristics for a leather industry nesting problem

Túlio A.M. Toffolo
KU Leuven, Department of Computer Science, CODeS & ITEC-imec
e-mail : tulio.toffolo@kuleuven.be

Tony Wauters
KU Leuven, Department of Computer Science, CODeS & ITEC-imec
e-mail : tony.wauters@kuleuven.be

Antonio Martinez-Sykora
University of Southampton, Southampton Business School
e-mail : a.martinez-sykora@soton.ac.uk

This study addresses a real-world nesting problem faced by leather cutting industries. Nesting problems are two-dimensional cutting and packing problems where irregular-shaped (and often non-convex) patterns must be cut out of some sheets (or packed into bins). The goal is to position these patterns within the available sheets (or bins) while minimizing the wasted area or maximizing the utilization.

Nesting problems are faced by different industries, with some having special characteristics. In the leather industry, sheets (here hides) are irregular and non-convex shapes, often containing holes. Hides are also composed of different quality zones, since they regularly contain bites, scars and other imperfections. These characteristics impose additional constraints to the problem, especially when considering that patterns may have different quality requirements.

Despite the practical applications and their impact, the amount of research on nesting problems with irregular bins is relatively low when compared to other cutting and packing problems. Some authors offer explanations, often pointing out the perceived difficulty to implement required geometric algorithms as one of the main reasons.

In this study, a real-word nesting problem with irregular bins is formulated as a mixed-integer program (MIP). Constraints handling both holes and different quality zones are included. The MIP is, however, incapable of handling real-world instances of the problems in acceptable time, motivating the development of constructive and local search (math)heuristics.

Heuristic algorithms employing the MIP were developed. Different heuristic decompositions for embedding the MIP were considered, taking into account rotations and the additional problem characteristics. During the constructive phase, each MIP positions an individual piece (or a small subset of them). Next, during the local search phase, these pieces are re-positioned by the MIP, which acts as a large neighborhood.

Experiments with different decomposition strategies and parameters are reported, showing the impact on solution quality and processing time of considering different subproblem sizes. The obtained results are then compared against those obtained by other heuristic algorithms for the problem.

Aiming at encouraging more research on nesting problems, a geometric toolbox including a robust no-fit polygon implementation (in Java) was produced with its source code being available online.

Acknowledgement : Work supported by the Belgian Science Policy Office (BELSPO) in the Interuniversity Attraction Pole COMEX (http://comex.ulb.ac.be).

Analysis and simulation of emergency departments: state of the art and prospects

L. Vanbrabant [(a, b)], K. Ramaekers[(a)], and K. Braekers[(a, b)]
(a) Hasselt University, (b) Research Foundation Flanders (FWO)
e-mail: lien.vanbrabant@uhasselt.be, katrien.ramaekers@uhasselt.be, kris.braekers@uhasselt.be

This abstract gives a brief overview of the state of the art on the analysis and simulation of emergency departments in hospitals. Based on this, research opportunities which will be addressed during my PhD are identified.

Emergency Departments (EDs) constitute an important component in a health care system. They are one of the main entry points of a hospital system, offering non-stop health care services to patients with various needs. From a social point of view, clearly it is crucial that EDs work efficiently, since timely and good services can save lives. However, EDs are large, complex and dynamic units which are difficult to manage. Moreover, EDs are confronted with a remarkable growth in demand due to the ageing population and the trend toward utilizing the ED for non-emergency care. Combined with the ever tightening budgets, this has led to the problem of (over)crowding in many EDs. Overcrowding occurs when the demand for emergency services exceeds the available resources in the ED. [2]

Currently, ED overcrowding is considered a major international problem. A lack of sufficient resources prevents timely and suitable services, leading to increased length of stay of patients, increased waiting times, patient dissatisfaction, increased probability of patients leaving the ED without treatment and increased stress levels of caregivers. To face these challenges hospital managers are continuously exploring opportunities to improve the efficiency of their health care system without reducing the quality of care. [1,2]

One of the most important measures of efficiency in an ED is patient throughput. From an operational perspective, patient flow refers to the movement of patients through the ED. The patient flow in an ED can be split up in three parts: intake, treatment and outflow. All three parts have an impact on patient throughput. The intake part can be seen as the arrival process in the ED. Arrivals are either by ambulance or by patient walk-in. The treatment part consists of triage, registration, placement in an ED bed, clinical assessment, treatment and diagnostic testing. The last part of patient flow, the outflow, is the disposition process. A patient can be discharged or admitted to an inpatient unit. [2,3]

Operations Research and Operations Management (OR/OM) techniques have been applied widely to analyse and optimise the decision making in health care organizations. For the analysis of EDs, simulation and queueing theory are the most popular methods. These techniques are suitable to investigate all three parts of patient flow. They have been extensively used to find improvements in the treatment phase e.g. capacity management, different triage systems, fast

track, bed planning. Research focusing on intake and outflow of the ED is rather scarce. However, these are the main problem areas according to ED staff, as is also indicated in previous research. Hospital managers have little impact on the inflow, because this is a stochastic and unpredictable process. Research on the inflow part focuses mainly on ambulance diversion, but this is prohibited in Belgium. The outflow process is the least studied part of patient flow through the ED. Different from the intake process, improvements are possible in the outflow. [2,3]

The flow out of the ED is often the bottleneck, causing very high throughput times. As indicated earlier, there are two types of outflow processes: discharge and admission. Patients that need to be admitted to an inpatient unit are a major problem in an ED. The inability to swiftly transfer care from the ED to the inpatient unit often forces these patients to stay in the ED and is therefore one of the most important causes of ED crowding. This phenomenon is called inpatient boarding in the literature. [2,4]

As indicated, most simulation models of EDs focus on the treatment (and intake) part while the outflow part is not included in the model. [4] Patient flow through the ED results from the interplay of many factors, so analysing the ED as a whole gives a more realistic view. Therefore, in this research project we will focus on a simulation model which integrates all three parts of an ED. Traditional information sources will be complemented with insights from data depicting actual process behaviour to construct a more realistic simulation model.

To analyse potential performance improvements of EDs, simulation-optimization will be used. Since EDs are complex and stochastic systems, leading to stochastic outputs, the system cannot be modelled analytically and the stochastic outputs can only be evaluated through simulation. Simulation-optimization, or simulation-based optimization, is the process of finding the best values of some parameters for a system, where the performance of the system is evaluated based on the output of a simulation model. [1] Simulation also makes it possible to investigate the simultaneous effect of different improvements. In this way, the simulation model can take interdependencies into account. Besides, it is possible to analyse and optimise different variables as an indication for patient throughput.

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Dynamic pickup and delivery for internal hospital logistics

W. Vancroonenburg, E. Esprit, P. Smet, G. Vanden Berghe
KU Leuven, Department of Computer Science, CODeS & imec - ITEC
e-mail: wim.vancroonenburg@kuleuven.be

Internal logistics and patient transportation are both critical services concerning the daily operation of any hospital. Given the diversity of logistic flows and scale of operation, managing such processes is challenging. While many logistic tasks occur frequently and follow daily routines, others prove far less predictable. Patient-related transports and other ad-hoc transports result from varying daily demand. Although many such transports are initiated from planned-in-advance activities, the process of planning and executing the actual transports often occurs *ad-hoc* (short notice).

This study presents a framework and model for the organization and directing of hospital transports based on the dynamic pick-up and delivery problem (DPDP). DPDPs represent a subclass of vehicle routing problems (VRPs) focusing on goods requiring pick-up from and delivery to specific locations by a fleet of vehicles (for further reference, refer to e.g. Berbeglia et al.(2010) [1] for a recent survey on the DPDP). The organization of logistic and patient transports in hospitals fits naturally within this problem class, while the specifics make it an interesting variant. For example, the concept of vehicle 'capacity' is variable for internal hospital logistics and depends upon the transport type (patients, goods, ...) executed. Patient transports are, in practice, rarely combined with other transports. Goods transports primarily involve transporting one or more carts (filled with medicine, surgical tools, food, linen, waste). Most important, 'vehicles' are in fact employees with their 'capacity' typically limited to transporting one to three carts, or a single patient. Furthermore, employees are also *skilled*: patient transports normally require an employee to hold some form of nursing or care giver certification. Similar certification may be required for the transport of certain medical goods. However, other goods transports are executed by logistic employees without any specific certification requirements.

The scope of this study is restricted to that of patient transports and ad-hoc goods transports. The contribution is twofold. Firstly, the potential of applying heuristic optimization techniques in such a dynamic and high throughput environment is investigated. Scheduling policies are applied which seek to optimize hospital key performance indicators (KPIs), formulated through a weighted sum objective function, before ultimately comparing the results against a widespread dispatching rule, *earliest due time first*, to determine whether efficiency may be increased. Secondly, a new approach for handling patient transports is investigated. Such transports are, as aforementioned, generally handled separately.

However, there are practical cases where it may be beneficial (in terms of hospital KPIs) to combine a patient transport with others. For example, combining two patients capable of walking in a single transport is perfectly feasible. Another example involves performing a small goods transport in combination with a patient transport.
Both research questions are investigated by means of a computational study for which a real-world hospital environment is used within which randomly generated (dynamic) problem instances are simulated.

Acknowledgements: Wim Vancroonenburg is funded by a postdoctoral research grant from Research Foundation Flanders – FWO. This study is funded by the iMinds ICON project 'AORTA' (`http://www.iminds.be/nl/projecten/2015/03/10/aorta`) and supported by the Belgian Science Policy Office (BELSPO) in the Interuniversity Attraction Pole COMEX (`http://comex.ulb.ac.be`).

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An exact and heuristic approach to the berth allocation problem in tank terminals

Thomas Van den Bossche, Greet Vanden Berghe
KU Leuven, Department of Computer Science, CODeS & imec-ITEC
e-mail: {thomas.vandenbossche, greet.vandenberghe}@cs.kuleuven.be

Juan Francisco Correcher, Ramón Álvarez-Valdés
Universitat de València, Dept. de Estadística i Investigació Operativa - Spain
e-mail: {juan.correcher, ramon.alvarez}@uv.es

Ships have increasingly become an essential component within international trade. When arriving at terminals, goods (such as containers) are processed for further transportation to inland locations. Port terminals compete to offer the best service to customers while guaranteeing the least ship waiting time possible. One of the most prevalent problems terminals face when managing their daily operations is the Berth Allocation Problem (BAP). This problem concerns the assignment of vessels to a specific berth and timeslot, while minimizing objectives such as total stay time or assignment cost. The berth characteristics, vessel dimensions and estimated arrival times restrict the number of eligible berths for each vessel. The BAP has been proven $\mathcal{NP}$-hard [1], posing challenges when handling large instances.

Academic work has focused primarily on the BAP in container terminals, with the ship handling times being fixed or dependent on the quay cranes assigned to process the cargo. Furthermore, the BAP may be classified as discrete, continuous or hybrid depending on the particular berthing layout. The discrete variant considers the quay as consisting of a finite set of berths or sections such that only a single ship may moor at each berth for any period of time. No quay partitioning exists within the continuous version and therefore vessels may berth anywhere along the quay. Finally, the hybrid variant considers the quay to be partitioned into a number of berths, with vessels capable of occupying more than one of these sections under certain conditions. Generally, terminal layouts considered in the literature consist of linear quays, implying the capability of this problem being modelled as a 2D bin-packing problem and presented in two-dimensional space. One dimension is spatial, i.e. the quay length, while the other is a temporal decision horizon.

While significant research has been conducted regarding the BAP in container terminals, little attention has been afforded to the BAP when concerning complex terminal layouts. The present work considers the discrete BAP in a tank terminal which consists of irregular quays. Adjacent, opposite and indented berths impose mooring and sailing restrictions to vessels in the terminal as a safety measure. Furthermore, the ship handling times depend on the levels of the tanks in the terminal and the setup time to start loading and unloading.

The aim of this work is to successfully address the BAP in terminals with irregular quays. An exact approach based on a Mixed Integer Linear Programming (MILP) model is introduced to tackle small instances and a heuristic approach based on the Multi-Depot Vehicle Routing Problem with Time Windows (MD-VRPTW) is employed when facing larger ones. Ships are represented as customers, while berths are considered depots. Experiments are conducted on benchmark instances derived from a real-world case.

The exact method proves capable of providing optimal solutions for small to medium-sized instances, whereas the heuristic delivers high-quality results in reasonable computational time. Future work includes extending the exact model to cope with additional real-world problem characteristics, such as the selection of the most beneficial tank regarding throughput to minimize total service time.

Acknowledgements: This work was supported by Agidens, Oiltanking Stolthaven Antwerp NV (OTSA), the Belgian Science Policy Oce (BELSPO) in the Interuniversity Attraction Pole COMEX (http://comex.ulb.ac.be) and Leuven Mobility Research Center and funded by research project 140876 of the Institute for the Promotion of Innovation through Science and Technology in Flanders (IWT-Vlaanderen).

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Spatial price competition in a waste management context

Jens Van Engeland
KU Leuven, FEB Campus Brussels
e-mail: jens.vanengeland@kuleuven.be

The market for waste management services cannot be considered as a perfect competitive market. Among others, environmental regulations and high investment costs do not make it easy for players to enter. Additionally, the market has a strong spatial dimension. Given a geographic area, the demand points (companies, waste recycling centres, cities ...) are fixed and once waste treatment facilities (suppliers) are established, they cannot be moved. Hence, consumers face transportation costs dependent on their distance from a certain supplier, giving rise to a differentiated product market. In this oligopoly environment, suppliers can respond by charging prices above marginal cost. Starting with the model of Hotelling [1], ample research has been done on these location and pricing problems. The focus was mainly analytical and thus considering simplified instances (constant and continuous consumer demand, straight line market area, infinite capacity ...) . This paper aims at numerical simulation of a real-life, 2D case with discrete customers and supplier capacity constraints.

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Overcoming the threshold problem in ascending combinatorial auctions

Bart Vangerven
KU Leuven, Faculty of Economics and Business
e-mail: bart.vangerven@kuleuven.be

Dries Goossens
Ghent University, Faculty of Economics and Business Administration
e-mail: dries.goossens@ugent.be

Frits Spieksma
KU Leuven, Faculty of Economics and Business
e-mail: frits.spieksma@kuleuven.be

Combinatorial auctions are auctions that sell multiple items simultaneously and allow bidders to bid on packages (sometimes called combinations or bundles) of items. We refer to de Vries and Vohra (2003), Abrache et al. (2007), and Cramton et al. (2006) for a survey of general combinatorial auction literature. Allowing bidders to create custom packages potentially increases economic efficiency and seller revenues. Indeed, when package bids are allowed, the exposure problem is avoided. However, economic efficiency is still hampered by the presence of the so-called threshold problem. The phenomenon that multiple "small" bidders (i.e. bidders on sets of items with small cardinality) appear not capable of jointly outbidding a "large" bidder, although the valuation of the bidders would allow the small bidders to do so. This effect is partly attributed to the fact that the small bidders are unaware of each other's presence, and therefore experience no incentive to keep bidding in an ascending combinatorial auction.

We study bidding behavior in ascending combinatorial auctions with threshold problems, using different levels of feedback. We do this in an experimental setting using human bidders. We vary feedback from very basic information about provisionally winning bids and their prices, to more advanced concepts as winning and deadness levels (see e.g. Adomavicius and Gupta (2005) and Adomavicius et al. (2012)), and even so-called coalitional feedback, aimed at helping bidders to overcome potential threshold problems. Hence, the main question we address is the following: "Does additional feedback help bidders overcome threshold problems in ascending combinatorial auctions?" We test this in different auction environments, varying the number of items and bidders as well as the severity of the threshold problem. To relate decision making in our experimental setting to individual differences, we create a personality profile for each bidder using the Big-Five Trait Taxonomy.

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Joint order batching, routing, and picker scheduling in manual order picking systems

T. van Gils [a, b], K. Braekers[a, c], K. Ramaekers[a], and A. Caris[a]
(a) Hasselt University (Research Group Logistics), (b) National Bank of Belgium
(c) Research Foundation Flanders (FWO)
e-mail: teun.vangils@uhasselt.be, kris.braekers@uhasselt.be,
katrien.ramaekers@uhasselt.be, an.caris@uhasselt.be

Upcoming e-commerce markets force warehouses to handle a larger number of orders, while the time to pick orders has shortened. In order to differentiate from competitors in terms of customer service, warehouses accept late orders from customers while providing delivery in a quick and timely way. By accepting late orders, the remaining time to pick an order is reduced. Furthermore, the order behavior of customers has changed from ordering few and large orders to many orders consisting of only a limited number of order lines [2].

Order picking management, in particular organizing efficient and effective systems to retrieve items from storage locations, has been identified as an important and complex planning operation. In this paper, three operational planning decisions, order batching, routing, and order picker scheduling, are integrated to manage order picking operations more efficiently. The order batching problem is concerned with deciding on rules defining which orders to combine on a pick list in order to minimize the order picker travel distance. The picker routing decision defines the sequence of items on the pick list with the aim of reducing the order picker travel distance. Finally, the order picker scheduling problem assigns batches to order pickers to ensure that all orders are picked before due time [4].

Traditionally, a sequential approach is used for these operational planning problems. The main focus in the literature is on individual warehouse planning problems. These topics have recently been reviewed by De Koster et al. [2], and Gu et al. [3]. While the number of publications dealing with one specific order picking planning problem is extensive, only a limited number of researchers examine different decisions simultaneously, even though the efficiency of different order picking planning decisions seems to be interdependent [3].

The main contributions of our study are the introduction of the order picker planning problem in warehouses, as well as the integration of order batching, picker routing, and order picker scheduling with the aim of improving order picking operations. The integrated order batching, routing, and order picker scheduling problem can be formulated as finding the minimum order picker travel distance by grouping a given set of customer orders into batches, sequencing the items in these created batches, assigning the batches to a limited number of order pickers, and sequencing the batches for each order picker to fulfill all orders before due time. To the best of our knowledge, we are the first to integrate order batching, routing, and order picker scheduling in order to make order picking

operations more efficiently. Since the warehouse planning problems of batching, routing and order picker scheduling seem to be interrelated [1,4], warehouse managers can benefit by integrating these planning problems. Optimizing each warehouse operation separately may lead to a suboptimal solution for the total warehouse.

A new mathematical formulation for the integrated batching, routing, and order picker scheduling problem is proposed. A linear mixed integer programming model is developed to formulate the integrated problem. The nonlinear model of Chen et al. [1] that integrates order batching and routing in a single order picker system is extended to multiple order pickers. Additionally, the nonlinear constraints are reformulated as linear constraints in order to create a linear optimization model for the new integrated problem.

Due to the complex nature of the integrated order batching, routing and order picker scheduling problem, solving instances of realistic size to optimality in a reasonable amount of computation time does not seem feasible. An efficient iterated local search (ILS) algorithm is introduced to manage the three operational planning decisions. To assess the performance of the proposed algorithm, the results of the ILS heuristic are compared with the results obtained using the mixed integer programming problem. The heuristic algorithm is analyzed for a wide range of warehouse parameters. The mathematical programming model can solve the integrated problem of order batching, routing and order picker scheduling only for small problem sizes, i.e. a small batch capacity and a limited number of customer orders. In the experiments, three different number of aisles and two varying number of storage locations per aisle are tested, as well as two batch capacity levels and two different order structures are tested to evaluate the performance of the ILS algorithm. Preliminary results show that the ILS algorithm is able to solve more than 99.1% of the tested instances to optimality.

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Acknowledgments

This work is supported by the Interuniversity Attraction Poles Programme initiated by the Belgian Science Policy Office (research project COMEX, Combinatorial Optimization: Metaheuristics & Exact Methods).

Considering human factors in planning problems for manual order picking systems: a state of the art

S. Vanheusden , K. Ramaekers and A. Caris
Hasselt University, research group logistics
{sarah.vanheusden,katrien.ramaekers,an.caris}@uhasselt.be

This abstract gives a brief overview of the state of the art on the integration of human-system interactions in manual order picking. Based on this, research opportunities are identified, which will be addressed during my PhD-study.

To stay competitive, companies try to minimize logistical costs as they play an important role in the total cost of a product. Warehouses, which play a vital role in the supply chain, can help to cut these costs by organizing their warehouse operations in an efficient and effective way. Trends such as shortened product life cycles, e-commerce, greater product variety and point-of-use delivery, expose warehouse management to new challenges. To overcome these challenges, companies need to continuously improve the design and operations of their warehouses and distribution networks. Over the years, scientific research has focused on the design and control of individual warehouse operations [4]

As warehousing plays an important role in the supply chain, warehouse operations need to fulfil basic requirements such as receiving, storing and retrieving stock keeping units for the fulfilment of customer orders. Sometimes value added activities are performed before the retrieved goods are assembled for shipment. Many design and operation challenges need to be considered and carefully implemented in order to meet capacity, throughput and customer service requirements [4].

Considering these four different warehouse activities (receiving, storage, order picking and shipping), order picking is the most costly one according to de Koster et al. [1]. Order picking, where goods are retrieved from storage or buffer areas to fulfil incoming customer orders, tends to be to be very labour intensive when it is done manually and very capital intensive when automated warehouse systems are used [4]. Although automating the order picking process is possible, the most popular order picking system in practice is still the low-level, picker-to-parts order picking system [1]. About 80% of all order processes are done manually because human operators are considered to be more flexible when unexpected changes occur in the process. Despite its popularity in practice, most research efforts have been performed in areas of AS/RS focusing on high-level picking rather than its manual counterpart [1].

In recent years, warehouses face changes in the order behaviour of their customers. To preserve high service levels, warehouses need to be able to fulfil many small orders for a great variety of SKUs due to trends such as e-commerce. To

stay competitive, companies are therefore accepting late orders from customers. This results in extra difficulties for order picking operations considering more orders need to be picked and sorted in shorter and more flexible time windows [1]. For order pickers this means that they are working under high time pressure and are expected to be productive and accurate at all times. Because of its labour-intensive, task-repetitive nature, order picking often leads to the development of musculoskeletal disorders which cause absence from work. As humans are the central actors in manual order picking, there is a great practical relevance for the incorporation of human factors in planning problems for manual order picking. The literature on order picking however is focused on individual planning problems such as layout design, routing, batching, storage assignment and to a lesser extent workforce scheduling, although the efficiency of these different planning problems are interdependent. Human-system interactions have been ignored in the existing planning and optimisation models, which results in an incomplete picture of real-world order picking [3].

In literature, order picking time is divided into four components: setup time, travel time, pick time and search time. As the travel time is considered the most dominant time component, other time components are mostly considered to be constant. By integrating worker characteristics, search time will be influenced by the concept of "learning by doing" [2]. In this PhD-study, the focus will be on optimizing warehouse activities by jointly considering different order picking decisions and simultaneously taking into account human-system interactions and order picker characteristics.

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Simulation based manpower planning: an introduction using SimJulia

Johan Van Kerckhoven*
Koninklijke Militaire School
Dept. Wiskunde
e-mail: johan.vankerckhoven@rma.ac.be

Ben Lauwens
Koninklijke Militaire School
Dept. Wiskunde
e-mail: ben.lauwens@rma.ac.be

Oussama Mazari-Abdessameu
Koninklijke Militaire School
Dept. Wiskunde
e-mail: oussama.mazari-abdessameu@mil.be

Filip Van Utterbeeck
Koninklijke Militaire School
Dept. Wiskunde
e-mail: filip.vanutterbeeck@rma.ac.be

Human resource management becomes more and more important. Not only do managers have to balance the needs of their organisation with the needs of their employees, but they also need to make well-informed manpower planning decisions. One part of manpower planning covers the short term, for example, setting up employee rosters such that the workload is appropriately distributed over the employees. The long term on the other hand concerns hiring and promotion strategies to meet the company's goals without alienating your employees, or to compensate for external policy changes such as an increase in the minimum retirement age.

Especially in the current day and age, these decisions are too important to be left to the manager's "gut feeling". Instead, he will rely on a mathematical model to provide the necessary insights to make appropriate decisions. Several types of models are possible here: Markov models, optimisation models using mathematical programming, simulation models, and system dynamics models. Each of these models can be used to model the transient state or the steady state of the system, and has its particular advantages and drawbacks for these tasks (see Jun Wang (2005)[1] for an overview).

Here we concern ourselves with a discrete event simulation model. In particular, we wish to illustrate, by means of a simple example, how we can use the programming language Julia[2], and in particular the SimJulia module[3], to

*Speaker

[1] Jun Wang, *A Review of Operations Research Applications in Workforce Planning and Potential Modelling of Military Training*, 2005.

[2] http://julialang.org/

[3] https://github.com/BenLauwens/SimJulia.jl

develop such a simulation. We also wish to shed some light on the development goals, both in the general, as in what we want to achieve, and specific, to which purpose(s) we will apply these results, sense.

Heuristic for real-time train rescheduling and local rerouting

Sofie Van Thielen
KU Leuven, Leuven Mobility Research Centre
e-mail: sofie.vanthielen@kuleuven.be

Pieter Vansteenwegen
KU Leuven, Leuven Mobility Research Centre
e-mail: pieter.vansteenwegen@kuleuven.be

During the last decades, there has been a growing interest in public transport, increasing the importance for accurate trains. Though timetabling can account for possible delays, in practice, external events regularly lead to primary and secondary delays. Once trains start deviating from their original schedule, conflicts are detected. Conflicts need to be resolved quickly in a way that disturbs the system as little as possible. Therefore, the impact on the whole network should be taken into account when preventing conflicts. In order to prevent conflicts, an advanced train management system (TMS), including train movement prediction, conflict detection and conflict prevention, is required to increase the accuracy of the rail network. Train movement prediction and conflict detection are already included in some advanced software. However, a good conflict prevention module is not present for practical use. This paper tries to complete this advanced software by including a good conflict prevention strategy.

Recently, many research has been devoted to real-time railway traffic management and thus conflict prevention. Some advanced optimization problems have been proposed to tackle the problem (e.g. [1], [2]). However, most of them lack the practical relevance of a closed-loop environment, indicating the optimization problems are not capable of including updated information during their running time. In [1] and [3], an outline of a complete TMS is discussed, but it has not been implemented in practice yet. In our paper, the focus is only on conflict prevention, since a conflict detection module is currently being implemented in Belgium.

The study area considered in this paper is Brugge-Gent-Denderleeuw, a large part of Flanders in Belgium. This area is approximately 91 km long and 32 km wide, consisting of 84 station areas ensuring 232 different platforms and 8850 block sections. The largest stations in this study area are Gent-Sint-Pieters, Oostende and Brugge. Note that the study area also includes shunt yards. The simulation considers trains between 6 and 7 in the morning, covering both passenger and freight trains, inducing a total of 181 trains. All data was delivered by the Belgian railway infrastructure manager Infrabel. For each delay scenario, 25 simulation runs are executed, each comparing different conflict prevention techniques. Each delay scenario introduces a random delay for α % of all trains. This random delay is taken from the exponential distribution with an average of three

minutes and a maximum of fifteen minutes.

This paper introduces a heuristic conflict prevention strategy including rescheduling and local rerouting. If a conflict is detected in a station area, the rerouting optimization procedure is started. This procedure will look for alternative routings through the station area in which the conflict was detected. This subproblem starts at the moment that the first of the conflicting trains enters the station area and ends when both trains have left the station area. For every train entering this station area during the outlined time period, alternative routes are considered, one per platform track. If a train has already entered the station area, its route is fixed and no alternative routes should be considered. The optimization problem is based on a flexible job-shop problem and solved optimally by IBM ILOG Cplex. If rerouting does not deliver a better solution in terms of secondary delays, the original routes are kept.

If the original conflict still exists after solving this routing subproblem, or when the conflict takes place outside a station area, rescheduling is considered in a heuristic way: when a conflict between two trains is predicted, it should be decided which of both trains will be delayed (extra) in order to give priority to the other train. Therefore, two possible situations need to be evaluated and compared. Consider two trains A and B that cause a conflict. First, train A is given priority and gets to use the block section first. This immediately implies that train B is delayed. Subsequently the progress of train A and B is examined. Specifically the duration of extra 'secondary' conflicts that train A (or B) will cause during the next hour are summed up. The sum of secondary conflicts caused by giving A priority over B is then compared to the situation where B is given priority over A. The decision that generates the least seconds of extra 'secondary' conflicts is executed. In order to limit the computation time to determine this decision, only secondary conflicts are considered, involving trains A and/or B, and no further conflicts. Results show improvements compared to a reference FCFS strategy of 2 % (for the delay scenario 20%) up to 8 % (for the delay scenario 80%). The heuristic is further extended to deal with multiple conflicts at once. However, results do not show significant improvements when dealing with multiple conflicts simultaneously.

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A step counting hill climbing heuristic for the practical Inventory Routing Problem

Kay Van Wynendaele
Conundra, Voordries 41, Oosterzele Belgium,
e-mail: kay.vanwynendaele@conundra.be

Simon Crevals
Conundra, Voordries 41, Oosterzele Belgium,
e-mail: simon.crevals@conundra.be

Mieke Defraye
Conundra, Voordries 41, Oosterzele Belgium,
e-mail: mieke.defraye@conundra.be

The inventory routing problem (IRP), has been studied extensively over the past decades. An overview of academic research in the past 30 years can be found in Coelho et al.[5]. Bell et al.[2] first introduced this notoriously difficult problem, which is described as a combination of vehicle routing and inventory management problems. The IRP decides (1) when the inventory of a customer is replenished, (2) the order quantity to be delivered, and (3) which routes are used to do so[4]. Despite the attention that the subject has received in the academic literature, Andersson et al.[1] point out that the existing methods differ greatly in practical relevance, and that inventory and transport are still commonly solved as separate problems in practice. Andersson et al. emphasize that there is a clear need from the industry for solution methods that are capable of handling the numerous practical constraints that arise in real-world IRP problems. Due to the complexity of the IRP, decomposition approaches are often used: the inventory problem and transport problem are then solved separately (sequentially or iteratively). As stated by Bertazzi and Speranza[3], joint optimization of inventory and transport can result in considerable cost savings, but is notably more complex. In our algorithm, we tackle this challenge, and simultaneously optimize inventory and transport planning. We present a powerful heuristic for solving practical inventory routing problems, based on the combination of a metaheuristic and a ruin & insert based local search strategy that particularly aims at solving large, complex, and practical IRPs. Our computational results show that our method succeeds in obtaining good solutions fast.

1 Acknowledgement

This research falls within the scope of the Conundra BITO project (Big data-driven dynamic Inventory and Transport Optimization), which is funded by IWT

grant I45053 of the Institute for the Promotion of Innovation through Science and Technology in Flanders (IWT-Vlaanderen) and Conundra (www.conundra.eu).

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A cost-sensitive regression evaluation framework

Wouter Verbeke
Vrije Universiteit Brussel
Faculty of Economic and Social Sciences and Solvay Business School
e-mail : Wouter.Verbeke@vub.ac.be

Cristián Bravo
University of Southampton
Southampton Business School
e-mail : C.Bravo@soton.ac.uk

Regression models are commonly being evaluated by either assessing the amount of error, e.g. in terms of Mean Squared Error (MSE) or Mean Absolute Error (MAE), or by indicating the explained amount of observed variability, e.g. in terms of (adjusted) R-squared value or Pearson correlation . However, the overall amount of error does not necessarily indicate how much use the model has for the intended purpose, since a prediction may although being far from exact still be useful for practical decision making. Neither does looking at the explained amount of variability ensure to obtain any benefit from the predictions made by the model, since in some applications the smallest estimation error may have catastrophic consequences. The use of a model and the impact of an error should therefore be assessed by accounting for the costs and benefits associated with the use of the predictions made by the regression model.

The aim of this research is to develop an evaluation framework to evaluate regression models from a cost-sensitive or utility perspective, in a complementary manner to existing statistical measures and allowing customization to the operational setting of the model. The presented regression performance framework generalizes existing measures and can be shown to instantiate to a number of traditional evaluation measures under specific sets of assumptions. As such the presented approach as well elicits the implicit, underlying assumptions when using traditional measures. The presented framework has been instantiated for use in a practical application, i.e. Loss Given Default estimation for Credit Risk Management.

In general, two main components can be identified that are taken into account by statistical evaluation measures when evaluating a predictive model. A first component concerns the prevalence of errors, which is typically accounted for by evaluating the model on a hold-out test set. The hold-out test set should be representative for the population on which the model is applied in order to provide an unbiased estimate of model performance.

A second component concerns the loss function, which determines the importance or weight of errors on individual observations in the test set when aggregating over all observations in the test set basically. For instance a squared

loss function assigns a higher weight to larger errors, whereas an absolute loss function assigns the same weight to all errors.

An evaluation measure P to assess predictive performance including these two components is generally defined by Equation 1

$$P = \int_E \ell(\varepsilon) \cdot p(\varepsilon) d\varepsilon, \tag{1}$$

With $\ell(\varepsilon)$ the error loss function determining the impact of an error ε and $p(\varepsilon)$ the probability density function over ε describing the frequency distribution or prevalence of errors. Integrating over the product of the weight function and distribution provides an evaluation measure.

Remark that the evaluation measure as defined in Equation 1 only depends on ε. However, as shown in the literature other elements beside error amplitude may be relevant and determining the impact of an error on model quality, whereas the size or amplitude of the difference in fact may, exceptionally, not be relevant at all.

From the approaches proposed in the literature, three factors are identified that determine the quality of a regression model. These should be explicitly included in a general performance measure, as such facilitating customized assessment of the quality of a regression model by capturing the application specific requirements. These three factors are : (1) the true value y of the target variable, (2) the predicted value of the target variable $\hat{y} = f(x)$, with f the predictive model, and (3) additional factors w determining the utility of a prediction for an instance x.

Explicitly accounting for these three factors leads to the generalized loss function $\ell(y, f, w)$ and evaluation measure P for assessing the performance of regression models, but as well classification models, as defined in Equation 2.

$$P = \int_Y \int_O \int_W \ell(y, f, w) \cdot p(y, f, w) dy df dz \tag{2}$$

Whereas the density function $p(y, f, w)$ is to be observed, the general loss function $\ell(y, f, w)$ needs to be specified for instantiating this generalized loss function to a specific measure. The MSE assumes a quadratic error loss function which is symmetric around zero and the MAD assumes a linear loss function symmetric around zero. Also the R-squared measure makes implicit use of a symmetric squared loss function to penalize errors on predictions, which are subsequently benchmarked to a maximum error, i.e., the squared difference between the observed true value and the mean observed value of the target variable.

However, loss functions do not necessarily need to be symmetric, and in many application settings are in fact asymmetric in nature. For instance under- or overestimation of demand in a supply chain management setting has significantly different implications with respect to costs and benefits resulting from adopting a production level based upon the estimated future demand. Underproduction because of underestimation will lead to understock and as such possibly to lost revenues. Overproduction as a result of overestimating demand will lead to overstock, which is associated with certain costs. These are typically however much smaller per item than lost revenues per item when underestimating demand. In a demand estimation setting therefore asymmetric costs are related to negative versus positive errors.

Optimal design of multiproduct batch plants using heuristic techniques

F. Verbiest
University of Antwerp, Dept Engineering Mgmt, ANT/OR Operations Research Group
e-mail: floor.verbiest@uantwerpen.be

T. Cornelissens
University of Antwerp, Dept Engineering Mgmt, ANT/OR Operations Research Group
e-mail: trijntje.cornelissens@uantwerpen.be

J. Springael
University of Antwerp, Dept Engineering Mgmt, ANT/OR Operations Research Group
e-mail: johan.springael@uantwerpen.be

Increasing pressure on supply chain performance forces production companies nowadays to take appropriate strategic decisions on e.g. plant design. As the construction of grass-root plants requires major investments, appropriate capacity assessments are needed. In our research, we focus on such strategic design decisions for multiproduct sequential chemical batch plants. Batch plants are typically equipped with tanks and reactors in which all the input material is treated for a certain period of time and then passed on to the next operation or stage.

The aim of the batch plant design problem is mostly to select the optimal number and size of equipment for every stage, out of a discrete set of available sizes, so as to minimise capital costs, taking into account design and horizon constraints. These constraints generally state that the designed plant should be large enough to produce a given demand on time. This design problem has been elaborately studied in literature, where it is generally formulated as an MINLP model that is solved exactly (e.g. using branch and bound or outer approximation algorithms) [1]. In previous research, we extended the objective function of this problem with additional cost components and included an additional design option: the installation of parallel production lines. These parallel lines are installed on one production site and operate independently but simultaneously with each other. The lines have the same processing steps or stages and hence products may be divided over the lines [2]. With this extension, the aim of the design problem is to determine the optimal number of lines to install, their design and the resulting product assignment to these lines. As these additional decisions increase complexity significantly, the problem becomes intractable for exact solution methods.

In this study, we present a preliminary version of the solution approach developed for the multiproduct batch plant design problem with parallel lines. We

employ local search techniques to find good solutions for the number of lines and the product assignments. Furthermore, the design of every line, i.e. the number and size of the equipment in every stage of every installed line, is determined using iterated local search.

Acknowledgements

Floor Verbiest acknowledges financial support from the Research Foundation - Flanders (FWO).

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Integrating the worst-case and best-case "Benefit-of-the-Doubt" class of Composite Indicators under the assumption of homotheticity

Pim Verbunt
KU Leuven, FEB Campus Brussels
e-mail: pim.verbunt@kuleuven.be

In this paper we propose an extension of the Benefit-of-the-Doubt (BoD) class of composite indicators (CIs). The Benefit-of-the-Doubt (BoD) method is a data-driven weighting approach inspired by the well-known Data Envelopment Analysis (DEA) that is increasingly used to construct composite indicators for country policy performance monitoring, benchmarking, and evaluation. The basic BoD-model evaluates countries in terms of their distance from the observed best performance under the most favourable "optimistic" evaluation conditions. In recent years, a "pessimistic" variant of the BoD-model has been proposed to evaluate countries performances in terms of their distance from the observed worst performance under the most unfavourable evaluation conditions. We propose an alternative BoD-model in which countries' distances from both the observed worst and best performers are taken into account. Specifically, by assuming homotheticity, we compute the projections of countries' upper countour sets of the observed worst practises on the lower countour set of the observed best practises. We argue that by taking country's distances from both the observed worst and best practices into account, we obtain a obtain a more balanced policy performance monitoring scheme. We further propose a decomposition to quantify the relative importance of both distance effects within the composite indicator.

Analyzing cost allocation techniques in intermodal barge networks for freight bundling

L. Verdonck
Hasselt University, Research Foundation Flanders (FWO)
lotte.verdonck@uhasselt.be

K. Ramaekers, A. Caris
Hasselt University
katrien.ramaekers@uhasselt.be, an.caris@uhasselt.be

D. Meers, C. Macharis
Vrije Universiteit Brussel, Research Group MOBI
Dries.Meers@vub.ac.be, cjmachar@vub.ac.be

Policy makers at European as well as regional levels express the need to stimulate intermodal transport chains. A growing market share for intermodal transport should mean a shift towards more environmental friendly transport modes, less congestion and a better accessibility of seaports. In order to improve the competitive position and efficiency level of intermodal transport, consolidation of freight flows is often suggested as it creates denser freight flows and leads to economies of scale. Multiple research efforts have been undertaken to investigate bundling networks in intermodal transport. The basic idea is to consolidate loads for efficient long-haul transportation (e.g. by rail, inland waterway barge or ocean-going vessel), while taking advantage of the efficiency of local pickup and delivery operations by truck [1].

Bundling networks require cooperation between multiple partners in the intermodal transport chain. In this context, the question rises how benefits may be allocated fairly among the participants in the cooperation. A great deal of scientific literature reports on the behavior of allocation methods in collaborations between shippers or carriers making use of unimodal road transport [4]. In intermodal barge transport various types of vessels with differing price structures may be considered for the bundling network. As such, applying the allocation methods which have been thoroughly studied in a unimodal road context is not so straightforward in an intermodal environment. Moreover, research on cost or savings allocation methods in intermodal transport is scarce. The main contribution of our research is thus to provide a first insight in the complexity of sharing cost savings fairly amongst shippers who bundle freight flows in order to reach economies of scale in intermodal barge transport.

Verdonck et al. [4] demonstrate that a wide range of possible allocation mechanisms exists. As each method has its specific benefits and drawbacks, it remains ambiguous which technique(s) could guarantee stability and sustainability in an intermodal freight bundling context. Moreover, the only scientific contributions

which study allocation mechanisms in intermodal transport make use of game theoretic methods to allocate costs fairly in a cooperative intermodal project consisting of terminal operating companies bundling freight [2,3]. For this reason, we perform a comparative analysis, applying four different allocation mechanisms to a case study. A comparison is made between two simple and straightforward cost allocation methods often used in practice (proportional and decomposition method) and two more advanced techniques based on cooperative game theory (Shapley and Equal Profit Method). In addition, special attention is paid to the stability of the found solutions.

The situation of three-, four- and five-partner coalitions is investigated, both for partners with an equal and an unequal amount of shipments. For these six situations, the case of a common barge trajectory and a common end terminal are studied. For a limited number of partners who share their complete barge trajectory and/or have equal shipment volumes, operationally simple cost sharing techniques like the proportional and/or decomposition mechanism may be utilized. Small shippers may prefer costs to be allocated by means of the Shapley value, since this division mechanism allocates a higher percentage of collaborative savings to companies with smaller shipment volumes. In addition, Shapley rewards partners contributing more to the collaborative goal. The Equal Profit Method, finally, provides the most equally spread transport cost savings. Because not all collaborations guarantee long-term stability, it is important to think in advance about the number of coalition participants in combination with the size of the vessel. Adding more partners to the coalition is not always favorable since this might lead to the use of a larger (and more expensive) vessel and the loss of long-term collaboration stability.

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The impact of timetabling on the efficient evacuation of a building

Hendrik Vermuyten
KU Leuven Campus Brussels
Department of Information Management, Modeling and Simulation
e-mail : hendrik.vermuyten@kuleuven.be

Jeroen Beliën
KU Leuven Campus Brussels
Department of Information Management, Modeling and Simulation
e-mail : jeroen.belien@kuleuven.be

Tony Wauters
KU Leuven, Technology Campus Ghent
Department of Computer Science
e-mail : tony.wauters@cs.kuleuven.be

Over the last decades, many different models have been developed for the building evacuation problem. Most of these models optimise the route choice for all (groups of) people that are in the building at the time of evacuation. Often the objective is to minimise the time that the last person exits the building. In developing these evacuation plans, these models assume the number of people present in the building and their locations as given. However, these two elements can be influenced through the university course timetable. For instance, spreading lectures evenly over the week or over the available rooms in the building can reduce the evacuation time, by reducing congestion on certain routes at particular times.

In this work, we integrate the evacuation process into the university course timetabling problem of the Faculty of Economics and Business at KU Leuven Campus Brussels. Our objective is to develop a timetable that maximises scheduling preferences, while simultaneously minimising the maximum of the evacuation time of each timeslot in the timetable. In a second step, our basic algorithm is extended to incorporate route choice in the decision making.

We develop a novel way to realistically describe the evacuation process, that explicitly includes congestion effects. It is based on the well-known network model used in building evacuation models. However, instead of assuming fixed arc capacities and a constant walking speed of evacuees, we use a flow propagation function that is based on the inverse relationship between walking speed and crowd density.

The solution approach consists of a metaheuristic that iteratively improves a start solution provided by on of our constructive methods. We have implemented three different constructive methods as well as three types of metaheuristics. We

have also implemented two ways of including route choice decisions into our basic algorithm.

Our model has been applied to the instance of the Faculty of Economics and Business and succeeds in finding a good solution which reduces the evacuation time significantly. Additionally, our model has been tested on the first group of seven instances from the International Timetabling Competition of 2007 (ITC2007). The results demonstrate a good performance of our algorithm on different sizes of real-world problem instances.

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