Welcome!

It is a great pleasure to welcome you in Louvain-la-Neuve for ORBEL 30, the 30th edition of the Belgian Operational Research Society's annual conference.

This conference will also be the opening event for the celebrations of the 50th anniversary of CORE, the Center for Operations Research and Econometrics (Université catholique de Louvain). CORE is one the oldest European research centers in the field of Operations Research. This initial event will be followed by numerous anniversary activities throughout 2016, see the CORE anniversary website, core50.be, for details.

ORBEL 30 offers a rich program including four plenary sessions which comprise *three* keynote talks and an Award Ceremony; 19 parallel contributed sessions; the annual ORBEL Board meeting and ORBEL General Assembly meeting; and social activities, including a conference cocktail and dinner, and a farewell reception.

We trust you will enjoy the talks of our three distinguished plenary speakers, whom we thank for agreeing to speak at our conference. The Award Ceremony will feature the *2016 ORBEL Award* for the best student thesis in Operations Research, an award sponsored by OM Partners; and the *2016 ORBEL Wolsey Award* for the best OR related open-source implementation, an award sponsored by N-SIDE.

Thanks to all of you, our 19 parallel contributed sessions will feature 76 contributed papers. As in previous years, relevant papers (about half of the total) have been assigned to *COMEX* (Combinatorial Optimization: Metaheuristics & Exact Methods) *sessions*, arranged in coordination with Prof. Bernard Fortz (Université Libre de Bruxelles).

The organization of this conference would not have been possible without the dedication of the Organizing Committee, whose membership you will find below, and the help of the administrative staff at CORE. In particular, we want to thank Emmanuelle Ide and Anne-Marie Pessleux for their invaluable help.

In addition, numerous individuals outside of CORE have helped make this conference happen. In particular, we would like to thank Vincent Blondel, recteur of the Université catholique de Louvain, for honoring us of his presence; ORBEL 29 conference chair, Prof. Kenneth Sörensen, of the University of Antwerp, for generously sharing his experience and promptly answering our numerous queries; and Prof. Michaël Schyns (Université de Liège) for the administration of the conference web site.

We wish you a very interesting and fruitful conference.

Maurice Queyranne, Conference Chair
François Glineur, Program Chair

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Plenary speakers

Eva K. Lee

Optimizing and Transforming the Healthcare System

IRisk and decision models and predictive analytics have long been cornerstones for advancement of business analytics in industrial, government, and military applications. They are also playing key roles in advancing and transforming the healthcare delivery system. In particular, multi-source data system modeling and big data analytics and technologies play an increasingly important role in modern healthcare enterprise. Many problems can be formulated into mathematical models and can be analyzed using sophisticated optimization, decision analysis, and computational techniques. In this talk, we will share some of our successes in early disease diagnosis, treatment planning design, and healthcare operations through innovation in decision and predictive big data analytics.

Eva K. Lee is a Professor in the H. Milton Stewart School of Industrial and Systems Engineering at Georgia Institute of Technology, and Director of the Center for Operations Research in Medicine and HealthCare, a center established through funds from the National Science Foundation and the Whitaker Foundation. The center focuses on biomedicine, public health, and defense, advancing domains from basic science to translational medical research; intelligent, quality, and cost-effective delivery; and medical preparedness and protection of critical infrastructures. She is a Distinguished Scholar in Health Systems, Health System Institute at Georgia Tech and Emory University. She is also the Co-Director of the Center for Health Organization Transformation, an NSF Industry/University Cooperative Research Center. Lee partners with hospital leaders to develop novel transformational strategies in delivery, quality, safety, operations efficiency, information management, change management and organizational learning. Lee's research focuses on mathematical programming, information technology, and computational algorithms for risk assessment, decision making, predictive analytics and knowledge discovery, and systems optimization. She has made major contributions in advances to medical care and procedures, emergency response and medical preparedness, healthcare operations, and business operations transformation.

Yurii Nesterov

Convergent subgradient methods for nonsmooth convex minimization

In this talk, we present new subgradient methods for solving nonsmooth convex optimization problems. These methods are the first ones, for which the whole sequence of test points is endowed with the worst-case performance guarantees. The methods are derived from a relaxed estimating sequences condition, and ensure reconstruction of an approximate primal-dual optimal solutions.

Our methods are applicable as efficient real-time stabilization tools for potential systems with infinite horizon. As an example, we consider a model of privacy-respecting taxation, where the center has no information on the utility functions of the agents. Nevertheless, by a proper taxation policy, the agents can be forced to apply in average the socially optimal strategies.

Preliminary numerical experiments confirm a high efficiency of the new methods.

Yurii Nesterov is a professor at Center for Operations Research and Econometrics (CORE) in Université catholique de Louvain (UCL), Belgium. He received Ph.D. degree (Applied Mathematics) in 1984 at Institute of Control Sciences, Moscow. Starting from 1993 he works at CORE.

His research interests are related to complexity issues and efficient methods for solving various optimization problems. The main results are obtained in Convex Optimization (optimal methods for smooth problems, polynomial-time interior-point methods, smoothing technique for structural optimization, cubic regularization of Newton method, optimization methods for huge-scale problems). He is an author of 4 monographs and more than 80 refereed papers in the leading optimization journals. He got the Dantzig Prize from SIAM and Mathematical Programming society in 2000, von Neumann Theory Prize from INFORMS in 2009, and SIAM Outstanding paper award in 2014.

Laurence Wolsey

MIP Reformulations: From Lot-Sizing to Inventory Routing

Starting from some basic results on simple lot-sizing problems both uncapacitated and with constant production capacity over time, we show how preprocessing, decomposition based on structure, and techniques such as multi-commodity reformulation of fixed charge networks and echelon stock reformulations allow one to significantly strengthen the formulation of more complicated problems such as inventory routing.

For a particular inventory routing problem involving a single production facility with initial stock, inventory constraints and capacitated production, multiple clients with initial stocks, deterministic demands and inventory constraints, served by a fleet of vehicles whose routes must also be determined, we demonstrate the use of these reformulations as well as developing new inequalities combining aspects of distribution, routing and inventory management. Some initial computational results will be presented.

The latter part of the talk is based on joint work with Pasquale Avella and Maurizio Boccia.

Laurence Wolsey works at CORE (Center for Operations Research and Econometrics, Université catholique de Louvain) and is emeritus professor of applied mathematics and operations research.

His main field of research is mixed integer programming, including theory, the development of branch-and-cut systems, and applications in production planning and scheduling and in network design. He is author of a textbook ”Integer Programming” Wiley 1998, as well as joint author with George Nemhauser of ”Integer Programming and Combinatorial Optimization”,Wiley 1988, and ”Production Planning by Mixed Integer Programming” with Y. Pochet, Springer 2006. He was editor-in-chief of the Mathematical Programming journal from 1999-2003.

Sponsors

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Practical details

Apart from the social events, the whole conference takes place in the AGORA building, located in the center of Louvain-la-Neuve, a five-minute walk away from the train station. Each room is equipped with a data projector; please bring your own laptop or share with a colleague. Twenty-five minutes are devoted to each plenary talk, including time for questions.

Each parallel session will be chaired by the last speaker. In order to allow inter-session hopping, we ask the chairpersons to follow the planned schedule as faithfully as possible.

Lunch on both days is a sandwich buffet on the conference site. The cocktail and dinner will take place in the *Loungeatude* restaurant in Louvain-la-Neuve, within walking distance from the conference site (directions will be provided on site). The farewell reception will take place at CORE, also within walking distance.

General Schedule

Thursday January 28

08:30-09:00	Welcome			
09:00-09:10	Opening			
09:10-10:10	Plenary session I Eva K. Lee, *Optimizing and Transforming the Healthcare System*			
10:10-10:30	Coffee break			
10:30-12:10	Parallel sessions TA			
TA →	*Optimization 1* (TA1)	*Healthcare & Bio-informatics* (TA2)	*Scheduling & Timetabling 1* (TA3)	*Vehicle Routing 1* (TA4)
12:10-13:30	Lunch (sandwich buffet)			
13:30-14:30	Plenary session II *2016 ORBEL and Wolsey awards ceremony*			
14:35-16:15	Parallel sessions TB			
TB →	*Optimization 2* (TB1)	*OR Applications* (TB2)	*Scheduling & Timetabling 2* (TB3)	*Vehicle Routing 2* (TB4)
16:15-16:35	Coffee break			
16:35-17:50	Parallel sessions TC			
TC →	*Optimization 3* (TC1)	*Location* (TC2)	*Networks* (TC3)	*Vehicle Routing 3* (TC4)
17:55-18:50	ORBEL General assembly			
19:00-	Cocktails and conference dinner (restaurant *Loungeatude*)			

Friday January 29

09:10-10:10	Plenary session III Yurii Nesterov, *Convergent subgradient methods for nonsmooth convex minimization*			
10:10-10:30	Coffee break			
10:30-12:10	Parallel sessions FA			
FA →	*Multiple Criteria Decision Analysis* (FA1)	*OR & Energy* (FA2)	*Supply Chain* (FA3)	*Transportation 1* (FA4)
12:10-13:30	Lunch (sandwich buffet)			
13:30-15:10	Parallel sessions FB			
FB →	*Linear Algebra & Graphs* (FB1)	*Decision, Risk & OR* (FB2)	*Logistics* (FB3)	*Transportation 2* (FB4)
15:10-15:30	Coffee break			
15:30-16:30	Plenary session IV Laurence Wolsey, *MIP Reformulations: From Lot-Sizing to Inventory Routing*			
16:30-	Closing and farewell reception			

Conference takes place in the **AGORA** building. All plenaries take place in room 12. Parallel sessions take place in rooms 01, 02, 03 and 04 (same number as track).

Legend for session codes: session TA1 refers to time slot TA for track 1 in room 01.

Detailed scientific program

Plenary session I - Thursday January 28, 09:10-10:10

Eva K. Lee, *Optimizing and Transforming the Healthcare System*

Parallel sessions TA - Thursday January 28, 10:30-12:10

Session *Optimization 1* (TA1)

◇ Surrogate Management in Mixed-Variable Derivative-Free Optimization
by Anne-Sophie Crélot, C. Beauthier, D. Orban, C. Sainvitu, A. Sartenaer 1
◇ A "What-If Analysis" Visual Tool to Compare Optimization Approaches
by Sascha Van Cauwelaert, Pierre Schaus, Michele Lombardi 3
◇ Towards the Complexity of Differentiation Through Lazy Updates in Local Search Engines
by Renaud De Landtsheer, Yoann Guyot, Gustavo Ospina, Christophe Ponsard 5
◇ Mining sequential data using constraint programming
by Tias Guns, Benjamin Negrevergne 7

Session *Healthcare and Bioinformatics* (TA2) – COMEX

◇ The impact of strategic alliances on the configuration of healthcare supply chains
by Julie Conings, Katrien Ramaekers, An Caris 9
◇ An Integer Programming formulation for the Polymorphic Alu Insertion Recognition Problem
by Luciano Porretta, Bernard Fortz, Bjarni V. Haldórsson 11
◇ Surgical case scheduling under generalized resource constraints
by Wim Vancroonenburg, Pieter Smet, Greet Vanden Berghe 12
◇ A Branch-Price-and-Cut Algorithm for the Minimum Evolution Problem
by Daniele Catanzaro, Roberto Aringhieri, Marco Di Summa, Raffaele Pesenti 14

Session *Scheduling and Timetabling 1* (TA3) – COMEX

◇ Conference scheduling - a personalized approach
by Bart Vangerven, Ward Passchyn, Annette Ficker, Dries Goossens, Frits Spieksma 15
◇ No-wait scheduling for locks with parallel chambers
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◇ A continuous-time model for scheduling gantry cranes in storage yards
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◇ A literature review on the open vehicle routing problem
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◇ Experimental Analysis of Metaheuristic Algorithms for the VRPTW
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◇ A study on the off-line tuning problem of a local search algorithm for the swap-body vehicle routing problem
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Plenary session II - Thursday January 28, 13:30-14:30

2016 ORBEL and Wolsey awards ceremony

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◇ Optimisation and uncertainty: comparing stochastic and robust programming
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◇ Random gradient-free methods for ranking algorithm learning
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◇ Efficient Methods for a Class of Truss Topology Design Problems
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◇ A critical look at Pichpibul & Kawtummachai's "improved Clarke and Wright savings algorithm"
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Yurii Nesterov,
Convergent subgradient methods for nonsmooth convex minimization

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◇ A Test for Single-Peaked Preferences
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Plenary session IV - Friday January 29, 15:30-16:30

Laurence Wolsey
MIP Reformulations: From Lot-Sizing to Inventory Routing

Surrogate Management in Mixed-Variable Derivative-Free Optimization

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Abstract

We consider the mixed-variable derivative-free optimization (DFO) problem

$$\begin{array}{ll} \min\limits_{x\in\mathbb{R}^n} & f(x) \\ \text{s. t.} & c(x) \le 0 \\ & l \le x \le u, \\ & \\ \text{where} & x = \left(x^{(r)},\ x^{(i)},\ x^{(d)},\ x^{(c)}\right) \\ \text{with} & x^{(r)} \in \mathbb{R}^{n_r}, x^{(i)} \in \mathbb{Z}^{n_i}, x^{(d)} \in D, x^{(c)} \in C. \end{array} \tag{1}$$

The objective f and constraints c are typically expensive to evaluate, may be nonconvex, and their derivatives are not available (e.g., black-box simulations). The sets D and C are finite ordered and unordered sets, respectively. We call $x^{(d)}$ the *discrete* variables, and $x^{(c)}$ the *categorical* variables. The constraints defined by C and D are nonrelaxable. Such problems arise in industrial applications such as aerodynamic applications. Those features limit the methods applicable to (1). In their survey on DFO algorithms and software, Rios and Sahinidis [3] point only 4 out of 22 DFO solvers considered that can handle noncontinuous variables. Among those 4 solvers 3 are designed for continuous and integer variables, and only the Mesh Adaptive Direct Search (MADS) implemented in the NOMAD software [1] handles categorical variables.

In addition, the solvers require a large number of function evaluations to achieve convergence and hence are not appropriate in our context. One way around this expense is to use surrogate models of f and c [2]. Surrogates should be relatively cheap to build and to evaluate. They may be used to determine promising candidates where the expensive functions should be evaluated.

Surrogates are already employed in Cenaero's MINAMO [4], a Surrogate-Based Optimization method (SBO) built upon an Evolutionary Algorithm (EA). In order to reduce the number of expensive function evaluations, the EA is applied to Radial Basis Function

(RBF) surrogates of f and c, within an iterative procedure that allows an update of the surrogates in the course of the optimization.

On the other hand, NOMAD has two main advantages: it handles all types of variables and it is supported by global convergence guarantees. However, it may require a large number of function evaluations to achieve convergence. In this talk we combine MINAMO's SBO as a surrogate within NOMAD in order to combine the advantages of both frameworks. We use surrogates in the two main steps of NOMAD: the poll step and the search step. Numerous candidates need to be evaluated in the poll step. Surrogates allow us to sort them in order of promise before starting the expensive evaluations. In the search step, RBF surrogates are minimized using the EA provided MINAMO, to determine promising candidates.

We present numerical experiments on analytical test problems to illustrate and compare the proposed strategies, using performance and data profiles. We finally formulate some recommendations based on our experience.

References

[1] M.A. Abramson, C. Audet, G. Couture, J.E. Dennis, Jr., S. Le Digabel, C. Tribes, The NOMAD project, Software available at https://www.gerad.ca/nomad/

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[3] L.M. Rios, N.V. Sahinidis, *Derivative-free optimization: a review of algorithms and comparison of software implementations*, Journal of Global Optimization, Springer, (2013) 56:1247-1293.

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A "What-If Analysis" Visual Tool to Compare Optimization Approaches

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In operational research, evaluation is of great importance in order to validate a given solving method with respect to existing ones (effect of an improved neighborhood in Local Search, a faster cut for Mixed Integer Programming, a global constraint in Constraint Programming, . . .). When reporting research results, a mandatory feature is the possibility to provide meaningful interpretations and analyzes from representative benchmarks. However, some communities (e.g., Constraint Programming) tend to limit the presentation of the results to tables, sometimes with only a few instances. This can drastically reduce the significance of the derived conclusions for the general case, while this should be the primary target when an evaluation is performed. The aggregation of the results is not a trivial question and it has a direct impact on the conclusions. Some indicators such as the arithmetic average of normalized measures are well known to bias the results [1]. An additional difficulty is the timeout given to the experiments. Some methods indeed become better if they are given more time while others are superior at the early stage of the execution.

A *performance profile* [2] is a tool that is more and more used to grasp a lot of conclusive information out of evaluated benchmarks. They are cumulative distributions for a performance metric that do not suffer of the aforementioned problems. Among other advantages, they directly provide a (cumulative) probability[1] for a solving method to be able to solve an arbitrary instance. Equipped with such a tool, one is clearly able to make better decisions regarding a solver based on quantitative evaluation data.

While performance profiles are very useful in practice, there exists no tool to generate and analyze them easily (what-if analysis on heterogeneous benchmarks) making an obstacle towards their broader usage by researchers. The operational research community would therefore greatly benefit from an easy-to-use web tool to build and export such profiles, with an easy and well-defined input format. The current work proposes such a web-based free and public tool.

In addition, research is sometimes lead towards wrong directions, trying to improve algorithms while there is actually no or small benefits to do so. A recent study [3] introduces a simple methodology for Constraint Programming to prevent falling into such pitfalls. It basically allows to estimate the gain provided by scaling down a given part of a metric

[1]Under the assumption the studied benchmarks are representative enough.

(e.g., time to perform a given domain filtering in Constraint Programming) of a solving process. The tool we propose can directly be used for such a study.

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Towards the Complexity of Differentiation Through Lazy Updates in Local Search Engines

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Differentiation is an efficient technique to quickly explore neighbourhoods in local search optimization. It allows evaluating neighbours without updating the model, eliminating in this way the need for backtracking (*technical* speed). Also, some invariants have better time complexity for differentiation than for update, because they do not need to modify their internal data structures.

In the context of generic CBLS tools, such as OscaR.cbls, LocalSolver, Comet, Kangaroo, etc. [1, 2, 3, 4], differentiation is hard to implement efficiently. First, all invariants need to provide differentiation mechanisms to deal with the moves performed by each neighbourhood. They can involve from one variable to any combination of variables of the types supported by the engine. Second, differentiation is also hard to apply in the presence of multiple paths linking the inputs to the objective functions. In such cases, differentiation needs to proceed more or less like regular model updates. Kangaroo supports such update process; it is called *"simulation"* [4]. Third, it can even be impossible to define these paths statically in problems like scheduling or routing with time windows. There are cycles in such models, so that differentiation actually requires updating the model to identify these paths, thus reverting to an update-and-backtrack technique.

We present an approach that often manages to reduce the complexity of invariant updates to the one of differentiation. In move-and-backtrack setting, successive updates of an invariant often annihilate each other. We therefore propose the idea of *lazy update* of the internal data structures of the invariants. Moves that have no impact on the output of the invariant are not performed on the time-consuming internal data structures. Instead, they are put on a backlog list. Opposite moves in the backlog annihilate each other and are never performed. Backlogs only needs to be performed when the output is impacted by an update.

This approach tries to reach the complexity of differentiation, although it will never have its technical speed. However, we claim that lazy internal updates are more generic than differentiation: they can be effective on a wider set of moves than differentiation, and can operate on any problem including routing and scheduling.

Lazy Updates Applied To The *Min* Invariant

CBLS engines represent combinatorial problems using search variables, invariants, and constraints. *Invariants* are code fragments implementing atomic expressions which must maintain, in an efficient way, one or more output variables according to the atomic expressions they implement, e.g.: `min, max, sum,`.... Our setting relies on a move-and-backtrack approach with lazy updates that are triggered only when a neighbour is evaluated, and partial propagation to update only the invariants that contribute to the evaluated objective function [5].

The invariant `min(values:Array[Int],indices:SetVar)` outputs the minimal value from an array of constant integers, considering only the positions in `indices`. An insert or delete on `indices` is typically $O(\log(n))$, performed by means of heap data structures, while the impact of these moves can be evaluated through differentiation in $O(1)$ (resp. $O(\log(n))$, but $O(1)$ if the delete has no impact on the output). We implemented a lazy `min` invariant: updates that are not impacting the output are backlogged. The backlog data structures have $O(1)$ complexity.

Comparative Benchmarks

We compared the efficiency of a model using the regular and the lazy `min` for the *uncapacitated warehouse location problem*. We profiled a round robin involving switching and swapping neighbourhoods. Measures with 1000 warehouse locations and 300 shops are reported below. 97% of the updates were annihilated.

Neighborhood	NbExploration	AvgTimeRegular	AvgTimeLazy	ratio
Switch	107	4.5 ms	1.6 ms	0.33
Swap	107	139 ms	51 ms	0.36

Future Work

We will apply laziness on invariants of OscaR.cbls featuring $O(\log(n))$ complexity or higher: `ArgMax`, `ArgMin`, etc. We will also try to extend the laziness to moves impacting the output of the invariant, to maximize the annihilation percentage, although increasing the annihilation percentage might not deliver relevant speedup on this case study, since it is already 97%.

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Mining sequential data using constraint programming

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Techniques from Operations Research are increasingly being used in machine learning and data mining. This is not just the case for typical machine learning problems such as classification and regression, which can be cast as optimization problems. Also for enumeration problems in data mining can techniques from OR be used, more specifically constraint programming techniques.

This submission concerns *constraint-based sequence mining*. Sequence mining aims to extract *interesting* subsequences that regularly appear in a dataset of sequences, where each sequence is an ordered collection of symbols. An example sequence from website logs is for example $\langle index.php, login.php, my - account.php\rangle$. Other application domains include clickstream data, query logs, annotated GPS logs and discrete event logs including any type of logs generated by machines or humans, as well as mining of biological sequences such as DNA and amino acides in proteins.

What makes a subsequence interesting often depends on the application at hand. The most straightforward measure of interestingness is that a subsequence must appear at least a number of times in the data, for example at least in 10% of the sequences. This is called a minimum frequency constraint. Many other constraints have been defined that can be used to incorporate domain-specific knowledge and to guide the search to *interesting* subsequences. In our work we divide constraints into four categories:

- *Constraints on the subsequence* these put restrictions on the structure of the subsequence. Typical examples include a constraint on the size of the subsequence (e.g. at least 2 elements in the sequence) or a regular expression that determines what possibly valid subsequences are.

- *Constraints on the cover set* where the *cover set* is the set of sequence in the dataset that contain the subsequence. The minimum frequency constraint is a constraint on the cover set, namely on its cardinality: $|cover(S, D)| \geq \theta$ for subsequence S and dataset D. Other cover set constraints often involve multiple datasets.

- *Constraints over the inclusion relation* where the inclusion relation determines when the subsequence is contained/included in a sequence of the dataset. For example, a *maximum gap* constraint requires that matching elements in the original sequence are not too far apart. For example, subsequence $\langle I, L, M\rangle$ is included in $\langle I, F, F, L, M\rangle$ with a maximum gap of 2 (namely the F, F between I and L), so this would not be a valid inclusion under a $max - gap <= 1$ constraint. Other constraints are minimum gap and maximum duration.

- *Preferences over the solution set* where a pairwise preference over the solution set expresses that a subsequence A is preferred over a subsequence B. Condensed representations and multi-objective optimisation fall in this category.

Other works have shown that constraint programming offers a very generic framework for constraint-based itemset mining, where an itemset is a set of symbols such as $\{bread, cheese\}$. This framework supports constraints on the itemset, on the cover set and preferences of the solution set; constraints over the inclusion relation are not relevant as the inclusion relation for itemsets is simply the subset relation. The constraint programming frameworks are more general than other, specialized, algorithms though this is often at the cost of scalability.

In a recent paper we study whether the same results can be carried over to sequence mining too. The main difference being that sequences are ordered and can have repeating symbols. The main difficulty is in modeling when the subsequence is contained in a sequence. This requires checking whether there exists a mapping from the symbols in the subsequence ot the symbols in the sequence, and there are $O(n^m)$ such mappings in theory. Furthermore, one typically needs to know that *an* embedding exists; this is a second order constraint that is not easily specified in constraint programming.

We propose two constraint programming formulations. The first formulation decomposes the problem such that for each sequence checking the inclusion of the subsequence is an independent subproblem. This formulation incurs quite some overhead and does not scale very well. To improve efficiency we introduces a second formulation with a new global constraint called *exists-embedding*. This constraint hides the complexity of the inclusion relation in a global constraint. This formulation is much more efficient but does not support additional constraints on the inclusion relation, as that would require changing the global constraints.

Computationally, we also show how our formulation relates to the concept of projected databases in specialised algorithms, and that we can use the related concept of local frequency to speed up the search in both formulations. The result, in the formulation using the global constraint, is a hybrid approach that incorporates elements from sequence mining algorithms within the constraint solving framework. Follow-up work has shown that enforcing the minimum frequency constraint within the same global constraint offers runtime efficiency on par with specialised methods.

Experiments compare the formulations to existing methods and demonstrate the tradeoffs in efficiency versus flexibility for different constraint-based settings.

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The impact of strategic alliances on the configuration of healthcare supply chains

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Up until now, most hospitals store goods in storage rooms located at the departmental level as well as in a central hospital warehouse. This configuration is called an in-house two-echelon system. Procurement and other logistics activities are usually handled by the hospital personnel itself. Purchasing and inventory related decisions taken by the departments are not integrated with similar decisions taken by the hospital warehouse. To better manage inventories, healthcare institutions should coordinate the logistics activities of the different echelons and aim at jointly optimizing inventory in all echelons [1][3].

Besides optimizing the internal hospital supply chain, hospitals tend to work together with other healthcare institutions and with suppliers to optimize inventory in the entire network [5]. Hospitals working together are regarded as a hospital cluster. A first manner to reduce inventory costs is to centralise procurement matters. Next to purchasing of supplies, hospitals can collaborate by clustering their inventory to reduce safety stock and consolidate order quantities, by jointly implementing JIT and stockless programs and by collectively investing in automation techniques [1].

The emergence of strategic alliances and outsourcing activities in the healthcare sector, raises questions concerning the optimal configuration of supply chains. [5] points out that the current hospital supply chain design with an in-house two-echelon system is not satisfactory. Hospitals clustering together feel the need for a common space to easier coordinate activities. [2] and [4] perceive the hospital's desire and envisage two ways to incorporate a shared accommodation in the supply chain configuration. Firstly, a regional distribution centre that delivers to several hospitals in the same region, can be added as a third echelon. Healthcare institutions can exploit this distribution centre themselves, but more likely is the outsourcing of the exploitation to a logistics service provider.

The addition of a third echelon to the chain increases handling activities as well as the need for storage space and poses challenges in coordinating decisions in all three echelons. As a second option, [2] and [4] consider to continue working in a two-echelon setting instead of moving towards a three-echelon system. In this configuration, the hospital warehouse will cease to exist. The regional distribution centre delivers directly to the hospital's departmental storage room. In this so called point-of-use distribution system, major distributors exploit the regional distribution centre and deliver supplies directly to the point of use.

Switching from the current configuration to one of the two above mentioned configurations, involves in both cases the establishment of a regional distribution centre. The founding of this centre raises loads of questions. One of these questions concerns the exact functioning of the regional centre. On the one hand, the regional centre can be seen as a wholesaler. Hospitals do not communicate with suppliers, all orders are communicated to the regional centre. On the other hand, the regional centre can be seen as an external stockroom. In this scenario, hospital orders are still communicated to the suppliers but receiving of these orders takes place in the regional centre. The functioning of the regional centre is not limited to one of these two options. Many other options are possible [1].

The configuration of the supply network has a major impact on the performance of the network. The coordination of operations between different members of the chain has been less covered in literature and the optimization of a multi-echelon system that meets the requirements of a healthcare institution has not yet been accomplished [4]. This PhD thesis will focus on the configuration of hospital supply networks as well as on the organisation of logistics activities within each of the echelons. The aim is to improve multi-echelon inventory policies inside the network.

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An Integer Programming formulation for the Polymorphic Alu Insertion Recognition Problem

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Alu (Arthrobacter luteus) forms a major component of repetitive DNA and are frequently encountered during the genotyping of individuals. The basic approach to find Alus consists of (i) alining sequence reads from a set of individual(s) with respect to a reference genome and (ii) comparing the possible Alu insertion induced by the alignment with the Alu insertions positions already known for the reference genome. The sequence genome of the reference individual is known and will be highly similar, but not identical, to the genome of the individual(s) being sequenced. Hence, at some locations they will diverge. Some of these divergences is due to the insertion of Alu polymorphisms. Detecting Alus has a central role in the field of Genetic Wide Association Studies (GWAS) because basic elements are a common source of mutation in humans. In [1] the authors investigate the Polymorphic Alu Insertion Recognition Problem (PAIRP) when Alu insertions are coming from a single individual and provided a polynomial time algorithm. Despite the enormous importance of the problem when Alu insertions are coming from multiple individuals the authors only provide an heuristic and they did not investigate the problem any further. In our work, we investigate the PAIRP relationship with the the Clique Partitioning of Interval Graphs (CPIG)[2]. Our results provides insights of the complexity of the problem, a characterization of its combinatorial structure and an exact approach based on Integer Linear Programming to exactly solve the correspond instances.

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Surgical case scheduling under generalized resource constraints

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The operating theatre (OT) is an important resource in any hospital. Surgery related services can represent more than 40% of hospital costs and revenues [1]. Consequently, a significant amount of attention is devoted to ensuring that this service is provided as efficiently and cost-effectively as possible. Managing and operating an OT is complex, requiring coordination of human and material resources, equipment and logistics. Careful scheduling is necessary to avoid delays and ensure high throughput.

This study presents a decision support model and algorithm for scheduling an OT. The model aims to support OT managers in their daily/weekly task of both scheduling (determining the date and time of) surgeries and assigning them to an operating room. This process generally differs between hospitals due to differences concerning infrastructure, policies and agreements with surgical staff. Therefore, this study emphasises the development of an adaptable general approach which may be customized for individual hospitals as required. One key contribution is the introduction of generalized resource dependencies that account for a variety of different resources, both human (surgeons, anaesthesiologists, instrumenting nurses) and material (portable imaging tools, operating lights). A lexicographic objective function models several performance indicators concerning the efficiency of the OT in addition to violations of (soft) resource constraints and personnel preferences.

A two-phase heuristic approach is presented which solves this decision support model [2]. This heuristic employs a schedule generation procedure within a local search algorithm to find high-quality solutions in a limited time. The approach has been implemented as a prototype in the OT management software product 'QCare OR', developed by Dotnext[1]. An experimental study on this approach was conducted using real-world data from a Belgian hospital and the subsequent successful results demonstrate the model's practical applicability and optimization potential.

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A Branch-Price-and-Cut Algorithm for the Minimum Evolution Problem

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The *Minimum Evolution problem* (MEP) is a $\mathcal{NP}$-hard combinatorial optimization problem which consists in finding a weighted unrooted binary tree having n leaves, minimal length and such that the sum of the edge weights belonging to the unique path between each pair of leaves is greater than or equal to a prescribed value. Here, we study the polyhedral combinatorics of the MEP and investigate its relationships with the Traveling Salesman Problem and Balanced Minimum Evolution Problem. We develop an exact solution approach for the MEP based on a nontrivial combination of both a parallel branch-price-and-cut scheme and a non-isomorphic enumeration of all possible solutions to the problem. Computational experiments show that the new solution approach outperforms the best mixed integer linear programming formulation for the MEP currently described in the literature. Our results give a perspective on the combinatorics of the MEP and suggest new directions for the development of future exact solution approaches that may turn out useful in practical applications.

Keywords: polyhedral combinatorics, network design, combinatorial optimization, mixed integer linear programming, branch-price-and-cut.

Conference scheduling - a personalized approach

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Scientific conferences are an essential aspect of (academic) research, as they allow researchers to present their work and receive feedback, as well as to learn from attending presentations (or discussion panels). Attending a conference requires considerable effort in terms of time and money from a participant. In order to ensure that this investment is worthwhile, it falls upon the organizers to ensure that the participants are able to attend the presentations of their interest. An often-heard complaint is that a participant is confronted with several preferred presentations overlapping at some time (i.e. a scheduling conflict), while at other times there is nothing of interest in the schedule.

A conference schedule is a schedule which assigns every presentation to a timeslot and a room. Consecutive presentations, i.e. presentations which are not separated by a break, in the same room are called a session. One popular approach to schedule conferences in practice is so-called track segmentation [3]. The organizer groups presentations that cover a similar topic into so-called tracks or clusters, which are then assigned to a room. Then presentations on different topics are in different rooms, and are in fact scheduled in parallel. If participants would only be interested in presentations from a single track, then they can stay in that track's room for the duration of the conference without experiencing any scheduling conflict. However, apart from difficulties in forming meaningful clusters, track segmentation is not very effective if participant preferences are diverse, and not restricted to one particular topic or method.

Our goal in this work is to develop a conference schedule that maximizes the participants' satisfaction (see also [1, 2]). We assume that each participant identifies a set of presentations, which he or she would like to attend. Then, we want to find a schedule that avoids as many scheduling conflicts as possible. In other words, we want to find a schedule that maximizes the attendance, given the participants' preferences. Phase one of our approach is then to solve an integer programming model that maximizes attendance, assuming of course that participants adhere to their preference profiles and freely switch between sessions. As a secondary goal, we want to minimize so-called session hopping. Indeed, confronted with multiple presentation of interest scheduled in overlapping sessions, a session hopper moves between several sessions in order to attend as many of his or her preferred presentations as possible. Session hopping can be seen as an indication of participants being confronted with a schedule which is not optimal given their preferences, and is typically experienced as disturbing by presenters and their audiences. Moreover, the session hopper still tends to miss parts of the preferred presentations, due to the time it takes to switch rooms and presenters not always starting at exactly the scheduled time. Phase two of our approach then, given the attendance from phase one, solves an integer programming model that minimizes the room switching. Finally, in phase three of our approach, although our focus is on the participant, we use an assignment-based formulation to also take into account presenter availabilities.

Summarizing, we consider conference scheduling at the level of presentations, which is a finer granularity than sessions, or even streams. We also account for session hopping, which is often assumed to be forbidden or non-existing, as opposed to regular attendee practice. Furthermore, we present a combined approach of assigning presentations to rooms and time slots, grouping presentations into sessions, and deciding on an optimal itinerary for each participant. This approach is based on solving integer programming models. It has been applied to construct the schedules of the MathSport International 2013 and the MAPSP 2015 conferences. Both are medium-sized events, with about 100 participants, and around 80-90 presentations.

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No-wait scheduling for locks with parallel chambers

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Problem statement

We consider the following scheduling problem that deals with ships passing through a lock: consider a single lock that consists of m parallel chambers. The chambers are each characterized by two numbers: their lockage time T_j and their capacity C_j ($j \in \{1, \ldots, m\}$). The term *lockage time* is the time needed to change the water level, thus allowing one or multiple ships to pass. The *capacity* refers to the number of ships that can be simultaneously served during a single lockage operation. Ships arrive at the locks at given times $t_1 < t_2 < \ldots < t_n$, and travel either in the upstream or downstream direction. Our interest here is exclusively on the existence of so-called *no-wait* schedules, i.e. schedules where each ship, upon its arrival, can immediately enter one of the chambers. The question we address is thus: does there exist an assignment of each ship to a chamber such that no ship has to wait?

Practical motivation

Scheduling locks is a problem that is receiving an increasing amount of attention, see e.g. [Hermans, 2014, Passchyn et al., 2016, Verstichel, 2013]. Most research that focuses on exact methods, however, concentrates on single-chamber locks. In practice, many locks consist of more than one chamber. On the Panama Canal, for example, each lock consists of two identical parallel chambers. Another example of locks with parallel chamber can be found on the Albert Canal in Belgium. Each of the locks there consists of three non-identical chambers.

A related problem is that of interval scheduling on parallel machines, where each chamber corresponds to a machine, and each ship to a job. Multiple intervals are associated to each job, one for each machine in the instance. Interval scheduling is a well-studied subject, see [Kolen et al., 2007] for an overview. A recent paper by [Krumke et al., 2011] deals with interval scheduling on related machines, of which our problem is a special case. Another interesting paper, by [Böhmová et al., 2013], investigates a variant of this problem where intervals corresponding to the same job have a point in time in common, as is also the case in our setting. They prove that deciding whether a schedule exists that schedules all jobs is NP-complete . They also mention a dynamic program (DP) given in

	2 arbitrary chambers	m identical chambers	m arbitrary chambers	m arbitrary chambers (m part of the input)
uni-directional	$O(n)$	$O(n)$	$O(mn^m)$	strongly NP-complete
bi-directional	$O(n^2)$	$O(n \log n)$	$O(mn^m)$	strongly NP-complete

Table 1: Summary of results.

[Sung and Vlach, 2005]; translated in our terms, this DP implies that the case where all ships travel in the same direction can be solved in $O(mn^{m+1})$ time.

Results

We consider four different problem settings. We distinguish settings with two arbitrary chambers, an arbitrary number of identical chambers, and m arbitrary chambers where m is either fixed or part of the input. For each of these settings we also consider both the uni-directional and the bi-directional case, i.e. the case where the ships all travel in the same direction or the case where each ship may travel in either direction respectively. Table 1 summarizes our results.

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A continuous-time model for scheduling gantry cranes in storage yards

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Automated warehouses which utilize rail-mounted gantry cranes (RMGC) for product handling face several costly challenges. Multiple cranes work in parallel to store and retrieve products to and from the storage yard via multiple input/output points. While each individual RMGC may serve the entire yard, they cannot cross due to being mounted on the same rail. Coordination between cranes, respecting safety distances between neighbouring cranes, complicate gantry operations. This ultimately results in certain inefficiencies such as poor-quality storage solutions and scheduling delays which heavily impact upon total costs. The optimization of gantry crane operations represents a significant industrial challenge whereby the primary objectives are to minimize such tardiness and storage costs.

Most previous studies exclusively address either location assignment for product storage or the scheduling of the cranes' operations. Indeed, [1] presented a continuous-time model for scheduling multiple yard cranes in a container terminal without considering the storage location assignment aspect of the problem. The present contribution rectifies the absence of a holistic approach to the problem, addressing both location assignment and scheduling in combination.

A continuous-time MIP formulation for scheduling gantry cranes in storage yards is presented. The model combines the location assignment for incoming products and the scheduling of each crane's operation, minimizing a weighted linear combination representing both the tardiness and storage cost. The model implements various realistic operational constraints, namely: the simultaneous retrieval and storage of products; multiple stacking configurations; multiple input and output points; and the dynamic assignment of cranes to operations. Each crane can traverse the entire yard provided safety distances among cranes are respected.

The model has been tested on a wide range of randomly generated instances which evaluates its performance based on various data settings. The proposed formulations may be extended to more general problems concerning the storage and retrieval of products and storage space allocation. Examples of such problems include yard crane or quay crane scheduling in container terminals and AS/RS related problems.

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Stepping horizon models for personnel rostering in integer programming

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Introduction

Personnel rostering is a well-known operational optimisation problem in which shifts are assigned to employees for a particular scheduling period. Typically, these assignments are restricted by a large variety of organisational and personal constraints, classifiable as either *counter constraints* or *series constraints* [4]. Academic models for personnel rostering often abstractly conceptualise the problem's practical characteristics. A prime example of this is considering only one isolated scheduling period, thereby contradicting common practice where personnel rostering inherently spans multiple periods. Consequently, models which do not include data from multiple scheduling periods often fail to meet the requirements imposed by practice. This study focuses on the effect of rostering constraints spanning multiple periods and proposes a new methodology for addressing this issue in integer programming approaches.

Static vs stepping horizon

Salassa and Vanden Berghe [3] denote models which consider a single isolated scheduling period as *static horizon* models. Contrastingly, models in which data from other scheduling periods is included are denoted as *stepping horizon* models.

To illustrate the difference between these two types of model, consider a series constraint which limits each employee to working, at most, four consecutive days. Information concerning shift assignments made during the preceding scheduling period is necessary for correctly evaluating the beginning of the current scheduling period. Evidently, when only the data from the current scheduling period is considered, any constraint violation occurring at the beginning of the current period remains undetected.

Glass and Knight [2] were among the first to identify constraint evaluation issues in static horizon models for personnel rostering. They empirically demonstrated the impact of considering assignments from the preceding scheduling period on one academic benchmark instance. However, at the time of this study a general stepping horizon methodology for personnel rostering did not exit in the state of the art academic literature.

Methodology and evaluation

To enable correct evaluation of counter and series constraints in stepping horizon models, the standard integer programming formulations are modified such that assignments from the preceding scheduling period, represented as constant values, may be included. For counter constraints, this is achieved by updating the constraint's ranges and by adding a constant derived from the constraint's cumulative value in previous periods. For series constraints, additional terms are added which correspond to the relevant assignments from the preceding scheduling periods. This methodology, established by Burke et al. [1] for heuristic optimization, is here adapted to efficient formulations for integer programming. The main advantage of this approach is that no additional decision variables are required in the stepping horizon model.

To analyse the impact of using the stepping horizon model compared to the commonly used static horizon model, a case study concerning rostering nurses in a hospital ward was analysed. Data was obtained for a one-year period from a software provider directly accessing the hospital's data. The hospital ward operates under an annualised hours policy, meaning each employee must work a required number of hours over the one-year period, without any specific monthly requirements. Experiments were conducted in which one-month periods were solved sequentially, thus requiring a stepping horizon model to respect the annualised hours policy and to correctly capture the series constraints at the boundaries of the one-month scheduling periods.

Computational results demonstrate that the proposed stepping horizon methodology closely approximates the optimal solution and significantly outperforms a static horizon model for the problem.

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The multiple-product multiple-depot vehicle routing problem with inventory restrictions

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Modern supply chains are under increasing pressure to ensure high service levels combined with low lead times. On the other hand, costs should be minimized to remain competitive, which requires a high efficiency of the logistic processes. A means to address these diverse challenges is through vertical integration of the different levels in a supply chain.

Clearly, the choice of depot locations should be aligned with the last-mile distribution process. However, and this has been all but neglected in the literature, the optimal vehicle routes of a distribution company are heavily influenced by its inventory control processes. Customers can only be served from a depot if sufficient inventory is available. In most routing models the inventory is treated as a black box. Products are assumed to be readily available at depots and different type of products are not distinguished. Thus, every products is assumed to be always available at every depot.

In our view, this presents an oversimplification of the complex logistic processes which decision makers have to face in reality. Stockouts are a typical problem in inventory management that cannot always be prevented. When a depot runs out of stock and is not able to deliver the demanded product, delivery might have to be organized by another depot. Likewise, not all types of products should be stored in every depot, since holding costs per products and depot might vary or the facilities differ (for instance cooled goods can only be stored at depots with cold chambers). Consequently, the challenge of this integrated inventory-routing view is to optimize the routing decisions taking into account the particular inventory situation in the various depots. We call this problem the multiple-product multiple-depot vehicle routing problem with inventory restrictions (MPMDVRP).

The problem is defined as follows: given a set of customers with known demands (for several products), given several depots, each with their stock levels defined, find the lowest-cost routes (starting and ending at one of the depots) for a fleet of vehicles such that all demands are satisfied, the capacities of the vehicles are not exceeded, and the total demand for each product served from each depot does not exceed the inventory of that product at the depot. This problem has not been described in the literature before, but it is closely related to several well-studied problems, most notably the multi-depot vehicle routing problem (MDVRP) and the inventory routing problem. In contrast to the inventory routing problem, we consider the inventory of the supplier rather than that of the customer. The most notable difference to MDVRP models is that customers might be delivered by more than one depot (e.g. the customer orders multiple products which are available only in different depots).

We implement the MPMDVRP as a mixed-integer programming problem and demonstrate that the inventory restrictions increase the complexity of the original MDVRP by several orders of magnitudes. Therefore, we develop a heuristics which is based on variable neighborhood search to compute near-optimal solutions for larger instances. For the variable neighborhood search we introduce new operators which are suited to deal with the inventory restrictions. Finally, we demonstrate the effectiveness of our algorithm by means of several case studies. The algorithm allows us to analyse the impact of different inventory strategies on the routing costs. By the comparison of different inventory scenarios, we aim to show in how far the decisions on the inventory level affect the decisions on the routing level. With these results we plan to analyse the potential of integrated inventory and routing decisions in modern logistic systems.

A literature review on the open vehicle routing problem

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Vehicle routing problem (VRP) is a combinatorial optimization problem which was introduced by (Dantzig and Ramser, 1959) and deals with the distribution of goods from depots to customers by generating a sequence of routes.Open vehicle routing problem (OVRP) is the generalization of vehicle routing problem (VRP) such that the vehicles do not require to return to the depot, or it follows the reverse order if returns. Although the key ideas for OPVR was introduced in (Scharge, 1981), the most studies has emerged after 2000s.In this study, we presented a comprehensive literature review on OVRP considering problem types and solution methodologies, and pointed the directions for future studies.

Experimental Analysis of Metaheuristic Algorithms for the VRPTW

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The vehicle routing problem with time windows (VRPTW) is an extension to the traditional vehicle routing problem for which a large number of heuristic procedures have been proposed. A general methodology to evaluate heuristic performance on these problems is still missing. In the current literature on vehicle routing, heuristic performance is commonly evaluated through tests performed on some benchmark problem set. Such an approach limits, however, any conclusions made to the specific problems considered in this benchmark set. Statistical meaningful conclusions can be obtained by applying an experimental design on the different levels of the various algorithmic parameters and by using the appropriate techniques for comparing results.

Only a small number of papers ([2],[7], ...) have made notion of using either design of experiment techniques or statistical tools for exploring data and testing hypotheses, even though this need for more scientific rigour in the operations research and heuristic community was already called for many years ago([1], [3],[4], ...). Hooker [3], for example, discussed the competitive emphasis used in testing heuristic algorithms and stated that while this may indicate which algorithms perform better, it does not give any explanation why these are better. Even more, the competitive approach only tells us which algorithm is better for the collection of test instances used in the experimentation stage. Without the use of proper statistical analysis, no conclusions can be made for unseen problem instances [5]. A heuristic algorithm performing well on some set of standard benchmark problems does not generalize to it working well on any problem set. Although these statements date back twenty years ago, they are still relevant today since a lot of current research still focuses on being competitive rather than gaining knowledge and understanding.

Current VRP research can therefore make a significant methodological progress by applying a statistical approach to obtain a more rigorous evaluation and gain a more complete insight in and understanding of the different results. This research aims at developing such a methodological framework. It proposes to apply a multilevel regression perspective in order to gain complete insights over the full range of algorithmic parameter values and problem characteristics. These insights will provide an understanding of how performance is affected by the addition of a component or by changing a parameter to another level, which combinations of parameter values and heuristic components perform well or not and how the problem characteristics influence this relationship with performance. Does the applied change lead to a better performing metaheuristic in a statistically significant way, or are any performance gains simply due to chance[7]?

A first analysis will be performed on a set of artificially generated VRPTW instances that are solved using a simplified version of the Adaptive Large Neighbourhood Search metaheuristic [6].

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A study on the off-line tuning problem of a local search algorithm for the swap-body vehicle routing problem

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In this work, we study the off-line parameter tuning problem of a local search-based metaheuristic for the swap-body vehicle routing problem. The algorithm contains a large number of neighborhoods. At each iteration, a neighborhood is randomly chosen with a probability proportional to its pre-defined weight, and a neighbor solution is generated based on it. Good values for these weights can be decided using an automated algorithm tuning/configuration tool such as SMAC (Sequential Model-based Algorithm Configuration, Hutter et al 2011). However, due to the large number of neighborhoods, given a limited budget for the tuning procedure, assigning a parameter for each individual neighborhood might be a bad idea. We discuss the ideas of an automated method to observe neighborhood characteristics during algorithm runs, and cluster these neighborhoods into groups based on the collected information. If the formed clusters are meaningful, using them should help to reduce the parameter configuration space without misleading the search of the tuning procedure. [1]

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Exact worst-case performance of first-order methods in convex optimization[1]

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In this work, we develop a methodology for automatically analysing the convergence properties of fixed-step first-order algorithms for solving the general composite convex optimization problem

$$\min_{x\in\mathbb{R}^d} f(x) + h(x),$$

where both f and h are convex functions. A typical situation consists in f being smooth and armed with a first-order oracle providing us with the value of its gradient, and h being convex (possibly non-smooth) and armed with an implicit (proximal) oracle. For example, one may think of f as a l_2-norm fitting term, and of h as a l_1-norm regularization.

In the past few years, first-order methods for solving such convex optimization problems have gained a lot of attention. As a matter of fact, their simplicity and cheap cost-per-iteration rendered them very attractive in practice, especially for large-scale optimization problems (i.e., when d is large) and when the accuracy is not the main focus.

On the theoretical side, even if the theory underlying those methods is becoming more and more mature, the analysis of such methods is often not very transparent, and may sometimes be very involved to develop. In addition to that, it is usually not clear whether the accuracy guarantees are very conservative or close to be tight.

In this presentation, we give an overview of a relatively recent trend, which consists in developing methods for automatically obtaining (computer-generated) numerical convergence proofs, for a variety of (first-order) algorithms. The idea rose in the recent works of Drori and Teboulle [1, 2], Lessard et al. [3] and Kim and Fessler [4]. In particular, we focus on the so called *performance estimation* framework [5, 6], which allows obtaining tight worst-case convergence guarantees. This approach is attractive in the sense that it numerically aims at providing at the same time worst-case guarantees (i.e., *upper-bounds*), and concrete examples of functions f and h for which those bounds are actually achieved (i.e., *lower-bounds*). In addition to that, it allows obtaining tight guarantees for fixed-step first-order methods involving a variety of different oracles — namely explicit, projected, proximal, conditional and inexact (sub)gradient steps — and a variety of convergence measures.

During the presentation, the links between the different methodologies [2, 3, 5, 6] will be emphasized, and we will illustrate how they can be used to further develop new algorithmic schemes, e.g., for obtaining better-performing first-order methods (in the worst-case sense) as proposed in [2, 4, 6, 7].

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Optimisation and uncertainty: comparing stochastic and robust programming

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Traditional optimisation tools focus on deterministic problems: scheduling airline flight crews (with as few employees as possible while still meeting legal constraints, such as maximum working time), finding the shortest path in a graph (used by navigation systems to give directions), etc.

However, this deterministic hypothesis sometimes provides useless solutions: actual parameters cannot always be known to full precision, one reason being their randomness. For example, when scheduling trucks for freight transportation, if there is unexpected congestion on the roads, the deadlines might not be met, the company might be required to financially compensate for this delay, but also for the following deliveries that could not be made on schedule.

Two main approaches are developed in the literature to take into account this uncertainty: make decision based on probability distributions of the uncertain parameters (*stochastic programming*) or considering they lie in a so-called "uncertainty set" (*robust programming*). In general, the first one leads to a large increase in the size of the problems to solve (and thus requires algorithms to work around this dimensionality curse), while the second is more conservative but tends to change the nature of the programs (which can impose a new solver technology).

This talk compares the two approaches on three different cases: facility location, unit-commitment, and reservoir management. On the implementation side, multiple specific algorithms have been implemented to solve stochastic programs in order to compare their relative performance: Benders' decomposition, progressive hedging, and the deterministic equivalent. When comparing stochastic and robust programming, many differences appear in many aspects, even though the literature about those is very scarce. (Furthermore, those two approaches are not incompatible: both can be used in the same optimisation model to take into account different parts of the uncertainty.)

Concerning solving time, stochastic programming quickly gives rise to intractable problems, which requires the development of more specific algorithm just to be able to solve them to an acceptable accuracy in decent time. What is more, the stochastic description of the uncertain values (with a discretisation of the probability distribution through scenarios) must cover all the possible uncertainty, otherwise the solution risks overfitting those scenarios, and is likely to have poor performance on close but different scenarios that may happen in practice — which imposes to use a large number of scenarios, which yields very large (and hardly tractable) optimisation programs.

On the other hand, by using specific uncertainty sets, robust programming yields programs that are only very slightly harder to solve, with an objective function that is very close to that of stochastic programming, but with totally different robustness properties: by using an uncertainty set computed from the scenarios, and not the scenarios themselves, it is able to withstand a much higher uncertainty than stochastic programming. However, when facing other types of uncertainty, this conclusion might turn untrue, with robust programming unable to cope with them and to bring interesting solutions to the table.

Random gradient-free methods for ranking algorithm learning

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The most acknowledged methods of measuring importance of nodes in graphs are based on random walk models. Particularly, PageRank, HITS, and their variants are originally based on a discrete-time Markov random walk on a link graph. According to the PageRank algorithm, the score of a node equals to its probability in the stationary distribution of a Markov process, which models a random walk on the graph. A certain random walk can be defined by its transition probability (given an edge with a source node which coincides with a current state, a probability of choosing the destination node by a surfer) and restart probability (given a vertex, probability of choosing this vertex independetly of a current state). For instance, in the original PageRank algorithm these probabilities are equal for all nodes in the case of a restart and are equal for all destination nodes in the case of a transition. Despite undeniable advantages of PageRank and its mentioned modifications, these algorithms miss important aspects of the graph that are not described by its structure.

In contrast, a number of approaches allows to account for different properties of nodes and edges between them by encoding them in restart and transition probabilities. These properties may include, e.g., the statistics about users' interactions with the nodes (in web graphs or graphs of social networks), types of edges (such as URL redirecting in web graphs) or histories of nodes' and edges' changes. Such information defines certain properties of nodes and edges and can be used for a more accurate evaluation of nodes' authorities as compared to the methods solely based on the geometric graph structure. Particularly, the transition probabilities in BrowseRank algorithm are proportional to weights of edges which are equal to numbers of users' transitions. In the general ranking framework called Supervised PageRank, weights of nodes and edges in a graph are linear combinations of their features with coefficients as the model parameters. Usually an optimization problem for learning the parameters is considered and solved it by a gradient-based optimization method. However, this method is based on computation of derivatives of stationary distribution vectors w.r.t. its parameters which potentially include calculating the derivative for each element of a billion by billion matrix and, therefore, seems to be computationally very expensive. The same problem appears when using coordinate descent methods. Another obstacle to the use of gradient or coordinate descent methods is that we can't calculate derivatives precisely, since we can't evaluate the exact stationary distribution.

In our work, we consider an optimization problem for learning the parameters and propose a two-level method to solve it. On the lower level, we use the linearly convergent method from paper by Nesterov and Nemirovski to calculate an approximation to the stationary distribution of the Markov process. However, it is not enough to calculate the stationary distribution itself, since we need also to optimize the parameters of the random walk with respect to an objective function, which is based on the stationary distribution. To overcome the above obstacles, we use a gradient-free optimization method on the upper level of our algorithm. We adapt the framework of random gradient-free methods to the case when the value of the function is calculated with some known accuracy. We prove a convergence theorem for this method. Also we investigate the trade-off between the accuracy of the lower level algorithm, which is controlled by the number of iterations, and the computational complexity of the two-level algorithm as a whole. For given accuracy, we estimate the number of arithmetic operations needed by our algorithm to find the values of parameters such that the difference between the respective value of the objective and its local minimum does not exceed this accuracy. In the experiments, we apply our algorithm to the problem of web pages' ranking. Details could be found at http://arxiv.org/abs/1411.4282.

Efficient Methods for a Class of Truss Topology Design Problems

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We propose efficient methods for a class of truss topology design problems for minimum compliance. We consider two dimensional planar ground structures with n free nodes and m potential bars together with the following dual formulation of the problem:

$$\min_x \|x\|_1, \text{ s.t. } Ax = f\,, \tag{1}$$

where $f \in \mathbb{R}^{2n}$ represents the load vector and the columns of $A \in \mathbb{R}^{2n\times m}$ describe the displacements associated with each bar. We especially focus on instances where the number n of free nodes is large, to allow for a fine-grained resolution of the resulting framework.

Our methods are efficient in two senses: (i) they enjoy low per-iteration complexity, as well as (ii) a linear total iteration complexity. Therefore they are well suited for large-scale applications.

It this talk, we describe our approach and present some preliminary numerical results.

An optimization model for allocation of municipal solid waste in Flanders

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Historical evolutions and inter-municipal cooperations decide on the current allocation of municipal solid waste (MSW) to treatment facilities in Flanders. Moreover, these facilities are unevenly spread across the region. Most of them are located in the western part of Flanders, while the main economic activity and population is situated in the centre. As a consequence, considerable amounts of waste are transported on the already congested roads. In the light of future waste policy developments, it is important to know what gains could be achieved by redesigning the current allocation in the first place. The proposed model is a straightforward application of an allocation optimization. All municipal waste should be assigned to a treatment plant, while respecting its capacity. The solution indicates that considerable savings can be achieved in the number of kilometers driven, and hence in operation costs.

Music generation with structural constraints: an operations research approach

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Music generation systems have attracted research attention since the advent of computing. They have become increasingly important, bolstered by rising global expenditure on digital music, which was over 64 billion USD in 2014 alone [Company(2010)].

Most music generation systems are based on statistical models and rules. A drawback of these early systems is their inability to synthesize music that possess global structure. When music does not have a clear direction or long-term coherence, it fails to hold the listener's attention and can be hard to follow. The computing power available to us today provides us with new opportunities to generate good sounding music with structure.

This talk will review state systems for generating music with structure, and describe an optimisation-based approach to music generation. The problem of structure has recently been tackled using deep learning, with mixed results. Guaranteed success has been achieved using optimisation algorithms that constrain the structure of the generated music. This approach is currently being examined in the authors' EU project MorpheuS[1].

Music generation as an optimization problem

When composing music is redefined as a combinatorial optimization problem, constraints can be used to enforce a larger temporal structure to a piece. For example, a solution could be a list of pitches constrained to a rhythmic template [Herremans et al.(2015)].

Measuring music quality An optimization-based music generation system needs a measure of quality of the output. What makes a piece of music sound good? This is a difficult and highly style dependent question. Three main approaches exist. The first one uses human feedback to get an evaluation score. While this might be the most intuitive approach, the human factor produces an enormous bottleneck. Secondly, rules from music theory can be quantified. This approach is only valid for a limited number of music styles that have well-studied formal rules such as counterpoint. A more robust approach is to use machine learning techniques to capture the style of a corpus or individual piece. Multiple ways of converting a Markov model into an objective function have been explored by [Herremans et al.(2015)]. This last strategy is most versatile when generating any kind of music.

[1] http://cordis.europa.eu/project/rcn/195685_en.html

Local search A proven strategy for solving a monophonic music generation problem with constrained structure is variable neighbourhood search (VNS). Starting from a piece consisting of random pitches, three move types—change one pitch; change two pitches; swap two pitches—together with a perturbation move are used by [Herremans and Sörensen(2012)] to navigate out of local optima. The algorithm outperforms a genetic algorithm approach.

Applications involving structure

Defining the music generation problem as one of optimization allows one the freedom to impose both hard and soft constraints. These constraints can be used to define different types of structure.

The tension profile serves as an example of narrative structure. The authors have designed a way to capture aspects of tonal tension based on the spiral array, a three dimensional model for tonality [Chew(2014)]. These tension profiles form one type of long term structure that could be implemented as a hard constraint in the existing algorithm.

Music with a particular tension profile is especially relevant to game music. Currently, music in computer games consists primarily of concatenated audio files joined together by cross-fading. When a user enters a danger/alert situation, tension levels rise and the music switches to another audio file. This could be done more smoothly by generating music on the fly with varying levels of tension.

Film music in another example of music that follows a structural narrative. The tension profile constraint approach can be used to create copyright-free background music for YouTube videos or stock music that follows the emotional narrative of the movie.

OR techniques in other domains of music research

Vast opportunities exist for applying techniques from the field of OR to music related problems far beyond music generation. Potential applications include instrument (for example, piano or guitar) fingering, genre classification, hit song prediction, automatic music transcription, multiple alignment, and many more.

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Application of Hidden Markov Models to music performance style classification via timing and loudness features

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Hidden Markov Models (HMMs) have been widely used in modeling time series data and, especially, in speech recognition [5]. In expressive music performance modeling, HMMs have served varied purposes such as generating expressive performances [2] and score following through machine listening [6]. We explore a novel use of HMMs for stylistic classification of performances of the same music piece. In Western art music it is common to distinguish performers and performance styles by their historically informed approaches, or lack thereof, as well as by the characteristics of the instrument being played. In Baroque music performance, we may differentiate recordings into those played on a Baroque period instrument (tuning around 415 Hz for concert A) and on a modern one (around 440 Hz). Aesthetic performing choices are often based on the performers' artistic and musicological approaches as well their previous exposure to other performances. These choices are commonly manifested in performers' use loudness and timing patterns, which are the elements of musical phrasing. Due to the availability of recordings and quantitative methodologies we may differentiate between the use of these expressive features between modern and Baroque performances. The questions we ask include: How well-defined is the division of Baroque and modern performances? Can quantitative methods capture if a performer plays in one style vs. the other? And, ultimately, can listeners perceive these differences? In this study we focus on quantifying performance style differences using HMMs with ground truth being the aforementioned division between Baroque and modern performances commonly found in Classical music culture.

The method is tested on performances of the first half (343 notes in total) of the Prelude of Bach's Suite in G Major (BWV1007). The excerpt was chosen for its isochronous rhythm and the lack of tempo or dynamic markings in the score. A dataset of twelve recordings performed by Anner Bylsma, Jaap Ter Linden and Peter Wispelwey on Baroque cello and by Mstislav Rostropovich, Jean-Guihen Queyras and Yo-Yo Ma on modern cello were collected. These performers were chosen because they have each recorded the piece at two different periods of their careers. Onsets for every note were manually annotated (twice and averaged) using Sonic Visualiser [7]. The timing ($log_2(tempo)$) is calculated per note duration and smoothed over each beat (four consecutive sixteenth notes) [1]. The loudness values (in sones) for each note played were extracted using a Short Time-Varying Loudness model proposed by Moore [3]. The set of features used therefore consist of the timing and loudness values separately, the timing and loudness combined, and the 1st and 2nd derivatives of each of these features, in order to study the "acceleration" (phrasing trajectory in our case) and jerk (rate of change of acceleration), respectively.

With the goal of automatically classifying the performances we train our models using the HMM implementation on scikit-learn [4]. We carry different experiments building classifiers models for baroque and modern styles according to the possible combinations of features. Our aim is to model the transition of expressive trends as possible expressive trajectories. We initially represent these trajectories as two different states within the hidden layer. We run experiments gradually incrementing the number of hidden states to 15. Once we have trained our baroque and modern models we test each performance by leave-one-run-out cross-validation and obtain the likelihood of each performance belonging to one or the other style model. We validate these models based on a randomized permutation test with 1000 iterations.

The validation test show that the classification results obtained after using the HMM models are significantly different (p ¡0.05) when the included features are loudness and the first and second derivatives of loudness (with 2 and 3 hidden states) or timing and the first derivative of timing (with 2 hidden states). The models trained using loudness and timing combined did not discriminate significantly. A main challenge faced in this study is the limited training data available. Further research should be carried with a larger dataset in order to validate the strength of this methodology. We show how by modeling performance styles using HMMs we may quantify and compare how well a performance fits one aesthetic style vs. another using different combinations of features, and how distant performances are from their respective styles. Further research could use this methodology to analyze the evolution of aesthetic trends by sequentially adding different performances to the models.

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Metaheuristics as a solving approach for the infrared heating in the thermoforming process

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Introduction

Sheet thermoforming is widely used in the plastic industry for several commercial applications. This process involves three stages: i) sheet reheat: the initial polymeric sheet is oven-heated to a softened state using radiative heat transfer, ii) forming: the heated sheet is deformed into the mold under the action of air flow, and iii) cooling and solidification: the polymeric sheet cools in the mold.

When heated by infrared radiation, the plastic sheet is transformed from glassy into a rubbery state. This hot state combined with the gravity creates a non-uniform thickness distribution in the plastic sheet. Adequate optimization of the heating stage can improve significantly the mass distribution in the finished part. One effective way to achieve a better uniform thickness distribution is to reduce the differences of energy intercepted and absorbed by the different areas of the thermoplastic sheet. The classical optimization methods of thermoplastics radiation have been the subject of many studies in finding the optimum solution of continuous and differentiable functions. These methods are analytical in the sense that they make use of the techniques of differential calculus to locate optimum points. However, practical problems usually involve objective functions that are not continuous, nor differentiable. Therefore, the classical optimization techniques have a limited scope for those applications. One way to circumvent this difficulty is to discretize the infrared source and the thermoplastic sheet into cells so one can use iterative processes to rapidly produce reasonable solutions.

The incident radiation on cell i of the thermoplastic sheet surface S_i is calculated according to the geometric orientation of surface and temperature t of oven heater cell j. View factors are required to obtain the energy for each area of the thermoplastic surface exposed to the infrared radiation. Assuming that surface S_j of the heater is separated by a transparent medium from surface S_i of the thermoplastic sheet, the amount of radiation

Q_i^j leaving area S_j and reaching area S_i is (see e.g. Erchiqui *et al.* [4]):

$$Q_i^j = F_{ij} \frac{S_i}{S_i} \sigma \bar{\epsilon} t^4, \tag{1}$$

where F_{ij} denotes the view factor, σ is the absolute temperature of the blackbody source of value $5.6710^{-8} W/m^2 K$, $\bar{\epsilon}$ is the average source emissivity of the material. Parameter r is the distance separating cells i and j, and t represents the temperature from the temperature set τ assigned to cell j. The view factors, given by the following

$$F_{ij} = \frac{1}{S_i} \int_{S_i} \int_{S_j} \frac{cos\theta_i cos\theta_j}{\pi \times r^2} dS_i dS_j \tag{2}$$

are required to calculate the energy on the thermoplastic surface exposed to the infrared source. Note that the evaluation of the double integrals of (2) is estimated with the Gauss method (see e.g. Dhatt and Touzot [2]).

Statement of the optimization problem

Let us recall that the energy received by each cell of the thermoplastic sheet from a single heating cell is given by (1). The criterion that evaluates a uniform distribution of the energy received by the thermoplastic sheet may be constructed as follows. The difference of energy received by two elements of the thermoplastic plastic sheet has an important influence on the quality of the final product. Obviously, the smaller are the differences between these elements the better is the quality of the product. The goal is thus to make the elements of the thermoplastic sheet receive the same amount of heat from the heating elements. One may to achieve this goal is to minimize the standard deviation of the energy, compared to the mean, received by the cells of the thermoplastic sheet. To be more explicit, we proceed as follows. The expression of Q_i^j may be written, for a given temperature τ_k to select from $\tau, = \{\tau_1, \ldots, \tau_k\}$ as $Q_i^j = F_{ij} \frac{S_i}{S_i} \sigma \bar{\epsilon} \tau_k^4$. It then follows that the total energy received by cell i of the thermoplastic sheet is $E_i = \sum_{i=1}^m Q_i^j$. If $\overline{x} = \frac{1}{n} \sum_{i=1}^n E_i$, then the goal is to minimize

$$f = \frac{\sqrt{\sum_{i=1}^n (E_i - \overline{x})^2}}{\overline{x}}, \tag{3}$$

such that any cell of the heating oven receives exactly one temperature from set and a temperature from may be used at most m times.

As stated, the above optimization problem is an extended version of the quadratic assignment problem. Indeed, the problem we are considering here may be viewed as seeking a mapping (and not a permutation as it is in the classical quadratic assignment problem) between the set of the temperatures and the set of the oven cells such that (3), a quadratic objective function, is minimized. It is known that the quadratic assignment problem is NP-hard (see e.g. Burkard *et al.* [1]). Therefore, the approximation approach is well justified as a solving method.

Metaheuristic approach and experimental study

Two meta-heuristic algorithms, the simulated annealing and the migrating bird optimization algorithms, as a solving approach, are proposed to distribute uniformly the energy intercepted by the material sheet.

Simulated annealing (SA) approach is a technique that uses the analogy of a metal cooling until a minimum crystalline energy is reached. The goal is to bring a system from an arbitrary initial state to a state with a minimum possible energy. The simulated annealing algorithm we implemented is resumed as below; for more details, see e.g. Pibouleau *et al.* [5]:

1. Generate an initial solution , and initialize T and c $(0 < c < 1)$;
2. Set the maximum number of iterations iter-max, the maximum number U of successive temperatures T the current solution is not improved, the successive number I of times the current solution is not improved for T;
3. Generate a new solution $\overline{S}$ in the neighborhood of S; $\Delta f = f_S - f_{\overline{S}}$;
4. if $\Delta f > 0$ then $S = \overline{S}$;

   else

   (a) generate at random $r \in [0, 1]$;

   (b) if $r < e^{-\frac{\Delta f}{T}}$ then $S = \overline{S}$;
5. Set $T = T \times c$ if I is reached;
6. Repeat Step 3 until either iter-max or U is reached.

The Migration Birds Optimization (MBO) was recently designed by Ekrem *et al.* [3]. The method is inspired from the shape of the flight in 'V' of the migrating birds. The property of flights of birds lies in the energy conservation. Indeed, when a bird beats its wings, it generates a draft which will make the bird behind have to supply fewer efforts to rise. The organization of the flight of birds is as follows: the bird in head leads the group for a certain period, and spends more energy than the rest of the birds. When it is tired, it moves behind the line of the group, and one of the birds behind takes the lead.

The parameters defining the above algorithm are n: the number of initial solutions, α: the number of neighbor solutions to consider, β: the number of neighbors to share with the next solution, x: the number of iterations to perform before changing the leader solution, and K: the maximum number of iterations the algorithm executes. The steps followed MBO may be resumed as below:

1. Fix α, β, x and K.
2. Generate arbitrarily n solutions, and place them in a V-shape.
3. Improve the leader solution by generating and evaluating α of its neighbors.
4. Improve the solution in the V shape by evaluating $(\alpha - \beta)$ neighbors with the β best solutions not used in the solution ahead.
5. Repeat x times Step 2 and 3.

6. Move the leader to the back of the group, and move one of the next solutions that are behind it to the leader position.

7. If K is not reached, repeat Step 2, 3 and 4.

In order to adapt the above two algorithms to our problem, a neighborhood of a solution must be specified, and there are many ways to do so. The structure of the one we adopted is as follows:

- ◇ Generate at random $r \in [0, 1]$;
- ◇ if $r \leq 0.5$, select at random two temperature locations i and j from the actual solution, and exchange the two corresponding temperatures;
- ◇ else select at random a temperature t from τ and assign it to cell i chosen at random from the (considered) current solution.

This technique of exploring the neighborhood space allows a certain diversification. Indeed, if a solution cannot be improved with the permutation of the actual temperatures, then a new temperature from the temperature set is generated to replace an arbitrary cell.

We conducted an experimental study to compare the two proposed algorithms (SA and MBO). We limited this comparison to the quality of the solutions they produced by setting the number of evaluated solutions to a maximum value of 10 000. We first conducted experiments to tune the parameters of SA and MBO. Second, we compared the quality of both algorithms on several types of instances. The two algorithms are implemented in Matlab-version 7.12.0 (R2012a), and executed on an INTEL 2.0 GHz Dual Core processor with a RAM of 8192 MB capacity. The details of the experimental study will be discussed during the presentation at the ORBEL meeting.

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Developing compact course timetables with optimized student flows

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Course timetables have an impact on the flows of students between consecutive lectures. Large flows can lead to congestion, such as long queues at elevators or stairwells, which in turn might delay lecture starts. Our research was motivated by the timetabling problem at the Faculty of Economics and Business of the KU Leuven Campus Brussels. Following a process of campus consolidation, all economic programs have been concentrated at a single location in the center of Brussels. This means that now over 8000 students follow classes in a single building, which has given rise to significant congestion problems at the elevators and the stairwells, when students travel to their next lecture. One possibility to reduce students flows would be to maximally spread the lectures over the day and over the week. However, students and teachers prefer compact timetables. This is especially the case for commuting students, as timetables with many free periods in-between or days with only a single lecture require a large amount of traveling towards and away from the campus.

Therefore, we develop a formulation for developing compact timetables that explicitly includes the travel time of students between their consecutive lectures. The lay-out of the building is represented by a graph in which a number of adjacent classrooms are grouped into a single node. The arcs then represent the corridors or stairs that connect the physical locations corresponding to the nodes they link, through which a flow of students can pass. It is thus possible that students need to pass through multiple arcs to reach their destination. Based on the empirical observation that increased density of pedestrians leads to a lower walking speed, we model arc-traversal times as flow-dependent. This means that a higher flow of students trough an arc results in a higher travel time over that arc. The travel time between consecutive lectures for a given series of students is then the sum of all the individual arc-traversal times of the arcs that are on the path between their given classrooms. Since the aim is to avoid delay in lecture starts caused by congestion, our objective function minimizes the maximal travel time between consecutive lectures over all series of students and timeslots.

Because of the complexity of our problem, we use a decomposition approach, where we split our model into two stages. The first stage minimizes the violation of preferences by assigning lectures to timeslots and rooms. The second stage then uses the timing of the lectures as given and minimizes the maximal travel time by reassigning lectures to rooms. Our model is applied to the dataset of the Faculty of Economics and Business of the KU Leuven Campus Brussels and is tested and validated with 21 adapted instances from the literature. In contrast to a monolithic model, the two-stage model can be solved using a standard IP solver and yields good quality solutions with significantly reduced student flows.

Integration of railway line planning and timetabling

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Railway planning is a complex problem that is typically split into several subproblems according to the planning horizon [Lusby et al.(2011), Lusby, Larsen, Ehrgott and Ryan]. Railway network design and line planning are long-term decision problems. Time-tabling, routing, rolling stock and crew scheduling are situated on the mid-long-term and real-time management is a short-term decision problem. These subproblems can be solved one after the other, where the output of the previous problem is used as input for the next problem. Each of these sub-decision problems is hard to solve to optimality for large and highly used networks. Nevertheless, many good working solution techniques are developed to solve these problems to near optimality. However, it is possible that the (near) optimal solution of an earlier problem does not give rise to a good solution for the next decision problem or does not even allow a feasible solution. A first option to avoid this inconvenience is to analyze the optimization process and output to find characteristics that explain the difference in quality in the next planning level. The conclusions of this analysis can then be included in the optimization process of the earlier problem. The advantage of this approach is that the output of the first problem is better suited for the second, the complexity of both problems remains the same and the resulting railway service performs better. Another option is to use an integrated approach of both decision problems. This approach provides one solution that is best for the combined problem. However, integration significantly increases the complexity.

Railway line planning is the decision problem in which is decided from where to where trains have to drive, in which stations they have to stop and how frequent they have to operate. The input for this problem consists of the railway network and the passenger demand from and to each station. To restrict the complexity of the problem, often a large pool of possible lines is available and the best set should be selected. Typical goal functions are the minimization of the passenger cost, the operator cost or a combination of both. The passenger cost is determined by the travel time and the necessary transfers for each passenger. The operator cost depends on the number and the length of the lines.

Railway timetabling is the decision problem in which the arrival and departure times of the trains in the stations are determined on a macroscopic level. If the microscopic layout of the network is taken into account, then the arrival and departure times at each point (e.g. each switch on the route of a train) has to be determined. The input for this problem is the railway network, the line planning and sometimes the routing of the trains through the network. During optimization, safety constraints are taken into account as well as (necessary) driving times between different points in the network. Capacity restrictions in the end stations of the network can also be considered during timetabling as well as the inclusion of supplements in the driving times. Different targets can be pursuit. Two main focuses are the minimization of passenger (planned or real) travel time and the robustness of the schedule, which is often formulated as the optimization of the buffer times between train pairs.

A line plan that behaves well for passenger cost or operator cost or both does not assure a robust timetable or a timetable that has good passenger travel times. When considering the microscopic layout of the network, it might even happen that no feasible timetable can be developed for a given line planning. The measures used during optimization of the line plan are only estimations of the real values. These real values can only be calculated exactly after timetabling.

Based on mathematical models, we developed an integrated approach of line planning and timetable optimization that improves a line planning in the way that the operator cost and the passenger cost are barely affected and such that the buffer times in the corresponding timetable significantly improve. By evaluating line plans based on optimized timetables, we found out that the driving time of a line includes information on how well the line plan will perform in case there are strict turn restrictions in terminal stations. So a line planning algorithm can be improved by including this insight. The operator and the passenger cost of the resulting line planning do not necessarily deteriorate compared to the original line plan, they can even be better than the original ones. This can be explained by the fact that the lines are typically chosen from a line pool and this pool is enlarged during the integrated optimization process. We tested our approach on the DSB S-tog network in Copenhagen (Denmark).

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Heuristic for solving detected train conflicts

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Though a timetable is assumed to be conflict-free, in real-time trains often experience delays due to unexpected external events. Conflicts imply that two (or more) trains want to use the same part of the infrastructure at the same time. Since timetables cannot encounter for all the delays that occur unexpectedly, trains should be tracked in real-time in case conflicts take place. In practice, this is done by dispatchers at the signal tower or at Traffic Control [1]. One dispatcher can only govern a small part of the network. One decision could have an impact on the entire network, especially if the rail network is very dense, which is the case in Belgium. Therefore the consequences for the entire network cannot be completely estimated and sometimes a (bad) decision results in huge knock-on delays. Therefore the entire network has to be considered for every decision, which is (almost) impossible to do exact [2]. Hence a heuristic is proposed in order to solve the problem in a reasonable time frame.

This work describes a heuristic that gives a solution for detected train conflicts by rescheduling trains [3]. The aim of the heuristic is to minimize the duration of delays caused by a conflict. Whenever a conflict occurs between two trains, there are two possibilities: either one of the trains (for example train A or B) can drive first. In order to evaluate the potential decisions, the progress of trains A and B during the next hour is examined. First it is evaluated what the effect is of delaying train B (or thus letting train A drive first). The direct interactions of trains A and B with any other train in the network is analyzed by calculating the total train delay. Subsequently the effects of delaying train A are examined in the same manner. Then the total delay of both choices is compared and the train that induces the least delay can drive first. Instead of the total delay, it is also possible to compare the two choices by total weighted delay (by type of train) or by total passenger delay (weighted by number of passengers).

A simulation makes it possible to compare the heuristic to several commonly used dispatching strategies. It includes delay scenarios that assume delaying a certain (given) percentage of trains. The trains that are delayed are randomly chosen from the timetable. They are given a random delay taken from the exponential distribution with average of five minutes and maximum of thirty minutes. Due to the (input) delays, conflicts will occur. These are solved by several dispatching strategies: First Come, First Served (FCFS) and priority to type of train (PTT), but also by the self-constructed heuristic. If a conflict occurs, FCFS gives priority to the train that requested that part of the infrastructure first. If multiple trains require the same part at exactly the same time, the train that leaves that part first, is given priority. The second strategy (PTT) accounts for the fact that slow trains should not drive before fast trains. If two trains cause a conflict, the train with the highest type may use the infrastructure first. The type of the train is a characterization of the speed and stopping pattern, for example Thalys, InterCity or PeakHour. It is assumed that the Thalys train has the highest type and the freight trains the lowest type. These two strategies are then compared to the self-constructed heuristic based on different evaluation criteria such as total train delay, total weighted delay (by type of train), total delay when leaving the study area and total passenger delay. The simulation momentarily utilizes the study area Brugge-Gent-Denderleeuw, which is a part of the Belgian railway network.

The heuristic can be further improved by also taking into account the history of the trains, for example how many conflicts they have already caused. It can also be interesting to investigate the effects on large networks. Further research should include the rerouting of trains. Even by only changing platform tracks in a station, it is already possible to diminish the amount of conflicts.

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An efficient procedure for parallel-machine scheduling with conflicting jobs

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We schedule a set $J = \{1, \ldots, n\}$ of n independent jobs on m identical parallel machines without preemption such that the maximum completion time of the jobs, or makespan, is minimized. Each job j has an associated processing time $p_j \in \mathbb{N}_0$ and is to be assigned to a single machine. The machines are gathered in set $M = \{1, \ldots, m\}$ and each machine can process at most one job at a time. An undirected graph $G = (J, E)$, subsequently referred to as *conflict graph*, is part of the input. If $\{j, j'\} \in E$ then jobs j and j' are *conflicting jobs*, and they need to be assigned to different machines. We call the resulting problem the parallel machine scheduling problem with conflicts (PMC). This problem is NP-hard because it contains both $P||C_{\max}$ (in the standard three-field notation of [2]) as well as the vertex coloring problem (VCP) as special cases. A feasible schedule exists if and only if the conflict graph can be colored with at most m colors. We will assume $m < n$ to avoid trivial solutions. Moreover, VCP is hard to approximate, and it can turn out to be hard to quickly find even a feasible schedule for a given instance. We conclude that PMC combines two very hard problems.

Informally, problem $P||C_{\max}$ can be seen as a "dual" to the bin packing problem (BPP), where the bin capacities correspond to the makespan and the number of bins corresponds to the number of parallel machines (see also [1]). A similar pairing can be observed between PMC and the bin packing problem with conflicts (BPPC), where the latter problem consists in packing items in a minimum number of bins of limited capacity while avoiding joint assignments of items that are in conflict. Clearly, BPPC generalizes both BPP and VCP.

We have developed an exact algorithm for PMC $\equiv P(\cdot, m)$, which proceeds as follows. First a lower bound $L(\cdot, m)$ and an upper bound (heuristic solution) $U(\cdot, m)$ on the minimum makespan are computed. When the heuristics do not succeed in finding a feasible solution, we invoke a feasibility test in an attempt to recognize instances with empty solution space. Conversely, when a feasible solution is found with one of the heuristics, then this solution is improved by means of a local search procedure. If $L(\cdot, m) = U(\cdot, m)$ then an optimal solution has been found, otherwise we start a binary search to identify the optimal objective function (which is in line with [1]). In this search procedure, we iteratively verify whether a feasible schedule exists with makespan at most $C^* = \lfloor \frac{L(\cdot,m)+U(\cdot,m)}{2} \rfloor$. This verification is established by means of a branch-and-price (B&P) algorithm. Concretely, let $F(C, \cdot)$ denote a set-covering formulation for BPPC in which the size of each bin is limited to C. Let $L_F(C, \cdot)$ denote the optimal objective value of the LP relaxation of $F(C, \cdot)$ (a lower bound). If $L_F(C^*, \cdot) > m$ then we replace the lower bound $L(\cdot, m)$ by $C^* + 1$. Otherwise, if the solution is integral then $U(\cdot, m)$ is replaced by the makespan of this solution (which is at most C^*), and if none of the previous two conditions holds then the B&P algorithm will branch and apply the same tests at lower levels of the search tree.

The algorithm solves all the benchmark instances of $P||C_{\max}$ (without conflicts) with very low average CPU times. For a newly generated dataset with conflict graphs, we have examined the difficulty of the instances as a function of the number of machines and the density of the graph. It turns out that the most difficult instances are those where the number of machines is close to the chromatic number of the graph.

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Integrating order picking process and vehicle routing problem

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Job scheduling in a production environment and order picking in a warehouse are two common problems in a company and are both well-studied in literature. These two problems have rather similar characteristics. In both problems, jobs need to be assigned to resources in such a way that an objective is met, e.g. cost minimization or service level maximization. The majority of concepts used in production scheduling are also used in order picking but with different terminology.

After jobs are produced or orders are picked, these need to be delivered to customers. Accordingly, production and distribution are interrelated and so are order picking and distribution. Recently, the integration of a production scheduling problem and a vehicle routing problem (VRP) at the operational decision level received more attention in scientific literature. A review on these integrated problems can be found in e.g. [1] and [8]. In an integrated *production scheduling-vehicle routing problem (PS-VRP)* both subproblems are solved simultaneously in order to obtain an overall optimal solution. Historically, these problems are solved sequentially which often lead to suboptimal solutions, as proved by e.g. [2], [7] and [10].

Most integrated studies consider a production environment in which jobs need to be processed on different machines and thereafter need to be delivered to customers using different vehicle routes. Low et al. [5, 6] investigate the integration of a practical scheduling problem in a distribution center with a VRP. Nevertheless, in their problem formulation production concepts are used. For instance, to calculate the processing time of an order a unit processing time of a retailer is multiplied by the demand of that retailer. However, in order picking processing times are not proportional to the demand requested. Travel times between different picking locations are the major component in order picking times [9].

A formulation for an integrated *order picking-vehicle routing problem (OP-VRP)* in a distribution center using the concepts related to a warehouse and order picking will be presented. In a warehouse different orders need to be picked by one or more order pickers. After completion of the picking process, orders need to be delivered within customer specified time windows using a fleet of vehicles. Due to the increase in the number of e-commerce transactions, customers order more frequently in smaller quantities. Customers expect a fast and accurate delivery within tight time windows [3, 4]. Therefore, the objective of the mathematical formulation is to minimize the total earliness and tardiness of order delivery.

The mathematical problem is solved exactly with CPLEX for an example with a small number of customer orders and vehicles. Furthermore, the value of integrating both problems is measured. A sequential approach is compared with the formulated integrated OP-VRP. In the sequential approach, first an order picking problem is solved. The output of this problem is used as input for a VRP which is solved afterwards. In contrast, in the integrated approach both problems are solved simultaneously. For example, the delivery time windows can be taken into account when the order picking sequence is determined. Preliminary results of the comparison between the two approaches will be provided.

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The capacitated vehicle routing problem with sequence-based pallet loading and axle weight constraints

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The capacitated vehicle routing problem with sequence-based pallet loading and axle weight constraints is an extension of the classical Capacitated Vehicle Routing Problem (CVRP). It integrates loading constraints in a routing problem and is based on a real-world transportation problem. The demand of the customers consists of pallets. These pallets may be placed in two horizontal rows inside the vehicle. Sequence-based loading is imposed which ensures that when arriving at a customer, no pallets belonging to customers served later on the route block the removal of the pallets of the current customer. Pallets are packed dense. This means that there may be no gap between two consecutive pallets in the container and that all pallets are alternately packed in the left and right row. Dense packing also entails that there may not be an open space between the front of the container and the first pallets that are packed. Dense packing is often imposed to increase the stability of the load since it restricts the moving area of the pallets considerably. The driver therefore needs to spend less time on securing the cargo than when pallets are spread over the vehicle. Furthermore, the capacity of a truck is not only expressed in total weight and number of pallets but also consists of a maximum weight on the axles of the truck. Axle weight limits pose a challenge to transportation companies as they incur high fines in the event of non-compliance. Weigh-In-Motion (WIM) systems on highways monitor axle weight violations of trucks while driving which increase the chances that axle weight violations are detected. Furthermore, trucks with overloaded axles represent a threat for traffic safety and may cause serious damage to the road surface.

The CVRP with sequence-based pallet loading and axle weight constraints was introduced in [2]. A Mixed Integer Linear Programming model (MILP) is proposed to solve the problem to optimality for networks of up to 20 nodes. To the best of our knowledge, this is currently the only paper that addresses the integration of axle weight restrictions in a VRP. In this presentation, an Iterated Local Search (ILS) methodology is proposed to tackle the problem on realistic-size instances with networks consisting of 50, 75 and 100 customers. An unlimited number of vehicles is considered. Characteristics of the vehicle fleet (measurements, capacity, mass, axle weight limits) are derived from information from a Belgian logistics service provider. The effects of integrating axle weight restrictions in a CVRP on total routing costs are analyzed by comparing the results with those of the CVRP without axle weight restrictions. The ILS consists of four procedures (Generate initial solution, Local Search, Perturbation, Acceptance Criterion). For more information regarding the general ILS framework, the reader is referred to [1]. First, an initial solution is constructed with a regret-2 insertion heuristic. In the next phase, local search is applied in which four neighborhoods (exchange, 2-opt, cross-exchange, relocate) are used. When a local optimum is reached, a new starting point for the local search is generated by perturbing the current solution. During perturbation, customer relocation is considered once for each customer, using a randomized objective function. An acceptance criterion determines after the local search with which solution the process continues. This criterion is based on Threshold Accepting. The ILS stops after α consecutive non-improving iterations. A non-improving iteration is an iteration in which no new best solution was found.

To validate the ILS, we compared the results of our algorithm with the optimal solutions for instances consisting of networks of up to 20 customers. In the majority of the instances, the optimal solutions were found by the metaheuristic. In case the optimal solution was not found, the optimality gap was very small with an average optimality gap of less than 0.2 %. The ILS is used to analyze the effects of integrating axle weight restrictions in a CVRP on instances of networks ranging from 50 to 100 customers. Results show that integrating axle weight restrictions does not lead to a large cost increase, while not including axle weight restrictions may induce major axle weight violations. On average, the CVRP with axle weight restrictions generated a cost increase of only 4.65% compared to the CVRP without axle weight restrictions. In some instances, axle weight violations could even be avoided with a cost increase of less than 1%.

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A critical look at Pichpibul & Kawtummachai's "improved Clarke and Wright savings algorithm"

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In their paper "An improved Clarke and Wright savings algorithm for the capacitated vehicle routing problem", published in ScienceAsia, 38(3):307–318, 2012, Pichpibul and Kawtummachai develop a simple stochastic extension of the well-known Clarke and Wright savings heuristic for the capacitated vehicle routing problem. Notwithstanding the simplicity of the heuristic, which they call the "improved Clarke and Wright savings algorithm" (ICW), the reported results are among the best of any heuristic ever developed for this problem.

We demonstrate that the results published in the paper could not have been produced by the ICW heuristic. We investigate several possible reasons for the discrepancy between the actual and the reported results of the heuristic and conclude that the most likely explanation is that the results have been deliberately misrepresented to window-dress an otherwise unexceptional heuristic.

Studying the reasons why this paper could have passed the peer review process to be published in an ISI-ranked journal, we have to conclude that the necessary conditions for a thorough examination of a typical paper in the field of optimization, are generally lacking. We investigate how this can be improved.

Iterated local search for the PDPTW: Improved benchmarks and a container transportation case

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One of the most prevalent problems within logistics and transportation is the Pickup and Delivery Problem with Time Windows (PDPTW). A fleet of vehicles must be routed to serve a set of transportation requests, while satisfying capacity, coupling, and precedence constraints. Academic work has focused on both exact and heuristic approaches to the PDPTW. The number of exact methods is rather limited and solving large-scale instances to optimality remains a difficult challenge. By contrast, heuristic approaches may potentially provide good quality solutions, even for larger instances, in reasonable computational times.
Consequently, the aim of this work is twofold.

The first aim is to successfully address large-scale PDPTW instances. To achieve this, a heuristic Iterated Local Search (ILS) approach is introduced which consists of an adaptive Ruin & Recreate neighborhood. Experiments are conducted on the extensively studied benchmark instances created by [1].

The second aim is the minimization of human working hours and operational costs. The heuristic is applied to a real-world PDPTW and tasked with efficiently routing a fleet of barges engaged in the pickup and delivery of container cargo, a problem discussed in depth by [2]. The present paper concerns a case study, concerning a logistics provider whose main terminal is situated along a heavily congested canal. The operator's main task consists of transshipping containers between deep-sea and inland terminals, thereby offering competitive services and costs compared to conventional truck haulage. The operator's inland location imposes constraints concerning varying lock waiting times and travel times. When requests can not be delivered on time, an alternative means of transportation must be found. This substitution is associated with a significant increase in operational costs.

The ILS heuristic's capability of improving academic instances while delivering high-quality solutions in practice prove the suggested approach's generality and applicability to various problems in shipping and logistics.

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Balanced Optimization with Vector Costs

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Consider the so-called balanced assignment problem. Given an $n \times n$ matrix C, an entry of C is denoted by specifying its row index i and its column index j $(1 \leq i, j \leq n)$. An *assignment* A is a set of n entries, such that every row and column in C contain exactly one chosen entry. The balanced assignment problem is the problem of finding an assignment A such that its *balance*:

$$\max_{(i,j)\in A} c(i,j) - \min_{(i,j)\in A} c(i,j)$$

is minimum.

Let us now generalize this problem by replacing each entry $c(i, j)$ with a cost-vector $\mathbf{c}(i, j)$ of length d, that is

$$\mathbf{c}(i,j) = (c_1(i,j), c_2(i,j), \ldots, c_d(i,j)), 1 \leq i,j \leq n.$$

Then, we define for an assignment A and each $k = 1, \ldots, d$:

$$\Delta_k(A) = \max_{(i,j)\in A} c_k(i,j) - \min_{(i,j)\in A} c_k(i,j).$$

Thus, $\Delta_k(A)$ refers to the balance in the k-th coordinate of the assignment A $(1 \leq k \leq d)$. Finally, we define the balance of assignment A as:

$$\Delta_{max}(A) = \max_k \Delta_k(A).$$

The objective in this *balanced assignment problem with vector costs* is to find an assignment A with minimum balance. It is easy to see that this problem generalizes the traditional balanced assignment problem which arises when $d = 1$.

Apart from being a natural generalization of 'traditional' balanced optimization problems, there are practical applications of balanced optimization problems with vector costs documented in literature. For instance, it is sketched in Kamura and Nakamori [1] how an industrial problem in the manufacturing of lenses gives rise to a (special) balanced assignment problem with vector costs.

Following Martello et al. [2], we see balanced optimization problems with vector costs as a family of problems, one member of the family being the balanced assignment with vector costs as described above.

For each problem in this family we show that (i) it is solvable in polynomial time when the dimension d of cost-vectors is fixed and (ii) it allows a 2-approximation algorithm.

Of course, there exists other combinatorial optimization problems for which a balanced version (with vector costs) makes sense. One can think of: q-uniform set systems, the assignment problem, the spanning tree problem, the connecting path problem, and the s, t-cut problem. We show that each of these problems is NP-hard, and that the existence of a polynomial-time 2-approximation algorithm for any one of these five problems implies P=NP.

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Active Learning of the Best Algorithm

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One is faced with a problem that needs solving and has access to multiple algorithms. Which algorithm to use? Figuring out which algorithm is best suited for a problem is a classic task in computer science. The standard approach to learning the best algorithm is to run experiments. A way to measure performance is decided, each algorithm is tested on a number of test instances, its performance is noted and the algorithm with best observed performance is chosen as best algorithm. After this off-line phase, the algorithm predicted to be best is used to solve new instances during the on-line phase.

Note that during the on-line phase feedback is collected in the form of new information about the predicted best algorithm. Every time it is used to solve an instance, the observed performances provide a more accurate estimate of the actual performance. The goal of this abstract is to propose a method to use the feedback generated during the on-line phase to predict the actual best algorithm with a higher accuracy than when based only on the off-line phase. This is done by modelling the problem as a multi-armed bandit problem. A secondary goal is to propose a formula to calculate the probability that the predicted best algorithm is also the actual best.

Consider the following active learning scheme: when presented with a new instance, pick the algorithm that is currently most probable to be the best algorithm. Initially the most probable best algorithm will be the one learned during the off-line phase. However, if its performance was overestimated during the off-line phase, this policy might over time lead to another algorithm being learned as best during the on-line phase.

More interesting than simply taking the observed mean into account is to also take information about the variance of the observed mean into account. Intuitively: in the long run it might be better to try an algorithm for which few observations have been collected instead of the predicted best. It might have gotten unlucky during those few observations. To pull this intuition up to a more formal level, the problem of learning the best algorithm can be formulated as an active learning problem. The goal becomes to pick at each point in time the algorithm that will lead to the overall smallest regret. Regret is incurred every time an algorithm is picked that turns out to not be the best.

When formulated as an active learning problem, learning the best algorithm has an attractive property: it is a standard multi-armed bandit problem. Each algorithm is an arm. Solving an instance with an algorithm is pulling a handle. The reward is the performance of the algorithm on the instance. Optimal strategies have been developed for the multi-armed bandit problem in terms of regret, therefore the problem of actively learning the best algorithm is solved optimally by modelling it as a multi-armed bandit problem.

An interesting question at each point in time, but especially when the off-line phase has just concluded, is: "What is each algorithm's probability of being the best algorithm?" The most relevant version of this question for the off-line scenario is: ”What is the probability that the algorithm predicted to be best is actually the best?”. An answer can be formulated when it is known which distribution describes the performances, using Bayesian methods.

Consider for example the Bernoulli distribution. When an algorithm's performance is measured in a success/fail manner, the probability of successfully solving an instance can be modelled using parameter p of a Bernoulli distribution. Consider two algorithms a_1 and a_2 with unknown probabilities of success p_{a_1} and p_{a_2}. S_{a_1} successes and F_{a_1} failures have been observed for a_1 and S_{a_2} successes and F_{a_2} failures have been observed for a_2. The probability of a_1 being the better algorithm is given by:

$$P(p_{a_1} \geq p_{a_2}) = \int_0^1 [\mathcal{L}(p_{a_2}|S_{a_2}, F_{a_2})(x) * \int_x^1 \mathcal{L}(p_{a_1}|S_{a_1}, F_{a_1})(y)dy]dx$$

with $\mathcal{L}(p_{a_i}|S_i, F_i)$ the likelihood function on parameter p_{a_i}. A likelihood function defines for each possible value that a parameter can take the likelihood that this value is the actual value, based on the observations. In the Bernoulli case a likelihood function can be defined using a Beta-distribution. Assuming a $Beta(1,1)$ prior, the likelihood function on parameter p, having observed S successes and F failures and with B the beta function is:

$$\mathcal{L}(p|S,F)(x) = \frac{x^S * (1-x)^F}{B(S+1, F+1)}$$

Calculating the probability of an algorithm being the best among multiple algorithms can straightforwardly be done by multiplying the probabilities of it being better than each individual algorithm. However, note that this approach is only correct when the observed performances of the algorithms are independent.

A regret-optimal method to actively learn the best algorithm was introduced by modelling it as a multi-armed bandit problem. In addition a formula was introduced to calculate the probability of an algorithm being the best algorithm, based on the observed performances, when is known which parametrised distribution the performances are being sampled from.

This research will provide the foundation for a method to actively improve the selection accuracy of an algorithm selection method by modelling the algorithm selection problem as a combination of two problems: splitting the problem space into subsets and learning for each subset its best algorithm.

Tightening linearizations of non-linear binary optimization problems

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A pseudo-Boolean function is a mapping $f : \{0,1\}^n \to R$ that assigns a real value to each tuple $(x_1, \dots, x_n)$ of n binary variables. Pseudo-Boolean functions have been widely used and studied during the last century and especially in the last 50 years, given that they model problems in a wide range of areas such as reliability theory, computer science, statistics, economics, finance, operations research, management science, discrete mathematics or computer vision (see [1], [2] for a list of applications and references). In most of these applications f has to be optimized, therefore we are interested in the problem

$$\min_{\{0,1\}^n} f(x), \tag{1}$$

which is $\mathcal{NP}$-hard even when f is a quadratic function.

It is well known that every pseudo-Boolean function f admits a unique multi-linear polynomial representation

$$f(x) = \sum_{S \in \mathcal{S}} a_S \prod_{i \in S} x_i, \tag{2}$$

where $\mathcal{S}$ is the set of subsets S of indices in $\{1, \dots, n\}$ such that $a_S \neq 0$. A common approach to solve problem (1) consists in linearizing (2) and then using integer programming techniques to solve the linearized problem. The *standard linearization* ([3], [4]) is a linearization method that consists in substituting each monomial indexed by $S \in \mathcal{S}$ by a new variable y_S, and adding constraint $y_S = \prod_{i \in S} x_i$ to the problem. This polynomial equation can then be linearized using inequalities

$$y_S \leq x_i, \forall i \in S \tag{3}$$

$$y_S \geq \sum_{i \in S} x_i - (|S| - 1), \tag{4}$$

which are equivalent with $y_S = \prod_{i \in S} x_i$ for binary variables x_i and y_S.

Problem (1) is therefore equivalent with

$$\min_{(x,y) \in P^*_{SL}} f(y) = \sum_{S \in \mathcal{S}} a_S y_S, \tag{5}$$

where

$$P^*_{SL} = conv\{(x, y) \in \{0,1\}^{n+|\mathcal{S}|} \mid (3), (4),\ \forall S \in \mathcal{S}\}. \tag{6}$$

It is known that when f consists of a single monomial, (3)–(4) together with the bound constraints $0 \leq x_i \leq 1$, $0 \leq y_S \leq 1$ (for all $i \in \{1, \ldots, n\}$ and $S \in \mathcal{S}$) is a perfect formulation of P^*_{SL}, in the sense that P^*_{SL} is completely described by these inequalities. For the general case when f consists of several monomials, it is hopeless to find a concise perfect formulation (unless $\mathcal{P} = \mathcal{NP}$). However, it remains an interesting question to try to obtain tighter formulations than the standard linearization, because these would provide better relaxation bounds and improve computation times for exact resolution methods.

Our main contribution is a perfect formulation for the case when f consists of two monomials. The formulation is obtained by adding the following inequalities, that we call *2-links*, for all $S, T \in \mathcal{S}$ such that $|S \cap T| \geq 2$

$$y_S \leq y_T - \sum_{i \in T \setminus S} x_i + |T \setminus S|. \tag{7}$$

Furthermore, we provide computational experiments showing that for the general case $|\mathcal{S}| \geq 2$, the addition of the 2-links to the standard linearization formulation provides significant improvements in the quality of the bounds of the linear relaxations and also on the performance of exact resolution methods.

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Budget-constrained pre-positioning of emergency relief supplies to minimize unmet demand

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The number of people affected by natural disasters or displaced by conflict, persecution, violence or human rights violations has been steadily increasing, doubling in a decade and reaching 82 million in 2015 [1]. Humanitarian logistics specializes in rapid provision of relief (emergency food, water, medicine, shelter, and supplies) to affected areas, so as to minimize human suffering and death [2]. Most of the research in humanitarian logistics optimizes post-event distribution of aid to people in need of assistance, e.g. [3], [4]. However, the disaster response could be further enhanced in the preparedness phase by advance procurement and pre-positioning of relief inventory at strategic locations. This allows to additionally speed up emergency assistance and save more lives by reaching areas that could be otherwise inaccessible. In turn, it makes the optimization problem much more complicated as it increases the number of decisions that need to be made, before even knowing the scale and particularities of the disaster.

This research therefore investigates pre-positioning strategies that determine the number, location and size of storage facilities, the quantities of various types of emergency supplies stocked in each facility and the distribution of the supplies to demand locations after an event, under uncertainty about if, or where, a disaster will occur. There exists some literature on the pre-positioning problem, e.g. [5], [6], [7], but more often than not the objective is to minimize costs, although this does not necessarily reflect the priorities of disaster relief. In this research we only require that the cost of opening the facilities, acquisition cost and transportation cost respect their budget limitations, while aiming to minimize expected unmet demand and response time.

We formulate the emergency relief supply pre-positioning problem as a two-stage stochastic mixed integer program. We assume that the uncertainties about demands, survival of pre-positioned supplies and transportation network availability can be modeled as a random vector with a finite number of possible realizations, called scenarios, with respective probability masses. This information can be predicted and/or derived from historical data. Since the problem is intractable for exact methods, we have developed a matheuristic that finds good solutions in a reasonable amount of time. We employ local search techniques to look for good location and inventory configurations (first-stage decision variables), and use CPLEX to find the optimal assignment of cities to the facilities that serve their demands (second-stage decision variables). Preliminary evaluation of the proposed method is performed using a case study focused on hurricane threat in the southeastern area of the United States, proposed in [6].

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Geographically grouping youth teams into football leagues

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The football leagues grouping problem (FLGP) concerns the assignment of teams to round-robin tournaments. The primary objective is to minimize the total travel distance of the teams while simultaneously respecting fairness constraints.

The FLGP is a challenge faced by numerous sport associations. The Royal Belgian Football Association (RBFA), for instance, organizes youth football leagues. Within East Flanders alone, these leagues comprise more than 500 youth teams playing approximately 5,000 matches. Therefore, reducing the total travel time and distance is very desirable, both logistically and economically. Observe also that the RBFA faces many instances of the FLGP: there are round-robin tournaments to be constructed for each age category of each province.

Prior to the start of each season, clubs enroll one or more youth teams to participate in leagues. Each team has a location (related to its club) and is assigned to a certain level, given by $l \in \{1, 2, 3\}$. These levels denote a team's estimated strength, with level '1' being used for the strongest teams. A league may contain teams from different levels, as long as the difference in level for each pair of teams in a league is at most 1. Furthermore, each league must comprise of between m^- and m^+ teams, where m^- and m^+ are problem parameters. It is undesirable for teams from the same club to play in the same league, however up to c^+ teams from the same club are permitted to do so, where c^+ is also a parameter – usually set to 2. Additionally, no team may travel more than a given time limit t^+ to another team's home venue.

Essentially, the FLGP can be described by a graph, where each vertex represents a team. Two vertices are connected by an edge if the difference in level between teams does not exceed 1, and if their locations are not farther away than t^+. The objective is to partition the vertex set into a set of cliques whose size respects both the minimum and maximum limits given by m^- and m^+ respectively, while minimizing the total weight of the cliques' edges. The resulting problem can be seen as a generalization of the clique partitioning problem with minimum clique size requirement [1, 2]. The main difference between the FLGP and the classical clique partitioning problem with minimum clique size requirement is that the FLGP imposes a limit on the number of teams from the same 'location' in a league (or clique).

Three integer programming formulations are presented: two compact formulations and one with an exponential number of variables, derived from [2]. The first two formulations are solved by CPLEX, while the last is solved by a tailor-made branch-and-price algorithm. CPLEX is employed to solve the master problem, whereas a specialized heuristic deals with the pricing problem of the column generation. In contrast to the approach of [2], the pricing problem is only solved by an integer programming solver when the heuristic fails to produce a reduced cost column.

Additionally, meta-heuristic methods are applied to generate feasible high-quality solutions. These solutions are subsequently employed to provide initial solutions and upper bounds when solving the formulations.

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Location, allocation, and routing decisions in an electric car sharing system

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The car sharing systems attract attention in urban areas with traffic congestion and high parking costs and they are based on the shared use of vehicles owned by a company or organization.

We focus on a one way electric car sharing system where we have a set of customers, each of which requests to travel from an origin point to a destination point at a certain time slot of the day by using the cars available in certain stations of a company. The system under consideration allows customers to leave the cars to a station different than the one that they are taken. The objective of the problem is to decide on the location of the stations and the proportion of the customer trips to be served in the most profitable way. Due to the battery restriction of the cars, a direct routing between the starting and the ending station of some trips might not be feasible. In this case, routing the customer via some intermediary stations provides an effective solution to the problem. The customers can leave the car with depleted battery at an intermediary station for charging and take a fully charged one to continue their trip. This structure requires additional decisions on the routes of the customers (that is, the order of the stations to be visited by customers) and the number of available cars at each station for each time slot. The profit function considers the revenue obtained by serving the selected customers and fixed location or operating cost of the opened stations.

We develop flow based and path based mathematical formulations for solving different variations of the problem and conduct computational experiments to evaluate the performance of our models.

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On the Piecewise Linear Unsplittable Multicommodity Flow Problem

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We talk about unsplittable multicommodity flow problems with piecewise linear cost functions. We focus on the case where these functions are convex. However, we also discuss the situation when the cost functions are non-convex. We begin by defining the convex unsplittable multicommodity flow (PUMF) problem. Let $G = (V, A)$ be a directed graph, with a set of nodes V, and a set of arcs A. Consider as well the set of commodities K, each $k \in K$ with a given origin o_k, destination d_k, and demand ρ_k. Each arc $a \in A$ has an associated cost function $g_a(l_a)$ of the load flowing through the arc l_a. This cost function is continuous, convex and piecewise linear, with the segments being represented by the finite set $S_a = \{1, 2, ..., |S_a|\}$. Each segment $s \in S_a$ has a lower and upper bound on the flow, represented by the breakpoints b_a^{s-1} and b_a^s. If finite, the breakpoint of the last segment of each arc $a \in A$, $b_a^{|S_a|}$, can be interpreted as the capacity of the arc. However, the case where $b_a^{|S_a|} = \infty$ also stands. A segment is also characterized by a slope c_a^s and an intercept f_a^s. As in the PUMF problem, the cost functions are convex, these values must be such that $c_a^1 > 0$, $c_a^s > c_a^{s-1}$ and $f_a^s \leq 0$, $f_a^s < f_a^{s-1}$. Moreover, as we consider the cost function to be continuous, we assume that $b_a^s c_a^s + f_a^s = b^s c_a^{s+1} + f_a^{s+1}$. We also assume that for every arc $a \in A$, $g_a(0) = 0$, and consequently, $f_a^1 = 0$. The PUMF problem is to find a single path for each commodity, such that the sum of the costs associated to the load of the arcs is minimized.

For $|K| = 1$, solving the PUMF problem is equivalent to solving a shortest path problem. However, for $|K| > 1$, the PUMF problem is $\mathcal{NP}$-hard.

We propose three new mixed-integer programming formulation for this problem: two Basic Models and a Strong one. The Strong Model gives a complete description of the associated polyhedron for the single commodity case.

We present computational experiments that show that the Strong Model produces very tight linear programming bounds for the multi-commodity case.

Hop-constrained electricity network design problems

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Electricity distribution networks can be subject to constraints that limit the number of intermediate nodes between some elements of the network (hop-constraints), in order to limit power losses. Representing hop-constraints in mixed integer optimization models can lead to an exponential number of constraints. We propose a compact extended integer model based on layered graphs modelling distances in a connected network. The resulting number of constraints depends linearly on the number of customers, feeders and maximum tolerated hops. This model allows to represent an approximation of power losses and can also be adapted to instances where edges have specific distances.

More precisely, we study the hop-constrained minimum margin problem in an electricity network. Given a set of feeders with a given capacity, the problem consists in designing a connected electricity distribution network, and to assign customers to feeders so as to maximize the minimum power margin over the feeders. Moreover, we impose a limit on the length of the path between each customer and its feeder (hop-constraints), in order to avoid too important power losses due to transportation.

Let V_f be the set of feeders, V_c the set of customers and L_{jd} the set of customers that can be connected to feeder j at distance d. Parameter pow is the power of each feeder, dem_i is the power demand of customer i and $L(d)$ is a discrete function representing the extra power to produce to compensate the loss on a path on length d. Finally the maximum number of hops is represented by D_{max}.

By defining binary variables x_{ijd}, where $x_{ijd} = 1$ if client i is assigned to feeder j at distance d, and , the problem can be formulated as:

$$\max \quad M_{min} \tag{1}$$

$$\text{s.t.} \quad pow - \sum_{i \in N_j} \sum_{1 \le d \le D_{max}} x_{ijd}\, dem_i . L(d) \ge M_{min} \qquad \forall j \in V_f \tag{2}$$

$$\sum_{j \in V_f} \sum_{1 \le d \le D_{max}} x_{ijd} = 1 \qquad \forall i \in V_c \tag{3}$$

$$x_{ijd} \le \sum_{k \in P_{ij(d-1)}} x_{kj(d-1)} \qquad \forall j \in V_f, d \in \{2, \ldots, D_{max}\}, i \in L_{jd} \tag{4}$$

$$x_{ijd} = 0 \qquad \forall j \in V_f, d \in \{1, \ldots, D_{max}\}, i \notin L_{jd} \tag{5}$$

$$M_{min} \ge 0 \tag{6}$$

$$x_{ijd} \in \{0, 1\} \qquad \forall i \in V_c, j \in V_f, d \in \{1, \ldots, D_{max}\} \tag{7}$$

Variable M_{min} represents a lower bound over the margin of all feeders through constraints (2) and has to be maximized (1). Constraints (3) ensure each customer is assigned to a feeder. The connectivity of each feeder's network is forced by constraints (4), representing the fact a customer i can be assigned to a feeder j at distance $d > 2$ only if there is another customer connected to i that is assigned to the same feeder j one distance unit closer. Constraints (5) avoid impossible assignments due to the network structure.

Numerical results of our model are compared with results of a cutting-plane algorithm presented in [1].

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Service network design and pricing for intermodal freight transport

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Intermodal freight transport has recently acquired a rightful position as an ecological choice and provided significant opportunities to generate economies of scale. Nevertheless, both the quality of its services and their corresponding prices have so far failed to attract the desired customer levels; a concern supported by the recent EU modal split figures. This obviously affects the critical market position of intermodal transport and, consequently, the target EU policies of modal shift in its favor.

In this paper, we consider the problem of simultaneously selecting the intermodal freight services to operate during a certain planning period and determining their associated tariffs perceived by the clients. To our knowledge, joint pricing and service network design problems are intrinsically poorly investigated in the literature, much less in the domain of intermodal transport. The decisions are tackled from the perspective of a typical intermodal operator; a service provider operating on a rail-inland waterways (IWWs)-road network. The problem belongs to the tactical decision horizon, regarding the underlying network infrastructure as fixed. Furthermore, a simple case of a monopoly is assumed as well as no price or service change reactions from the only competitors: trucking companies. A key design question in this problem is indeed to model the demand volumes of the services in question. For this specific issue, the bilevel progamming framework is decided upon; a concept scarcely utilized in intermodal transport-related topics, though powerful in hierarchical and non-cooperative decision schemes. On the higher level, an intermodal operator seeks to maximize his profit through service design and pricing decisions, while on the lower level, the target customers seek to maximize their utility through service choice decisions between the offered intermodal and the already existing trucking services.

In order to steadily approach the problem, we start by modeling the higher level as a static service network design problem, while fixing the demand levels and, consequently, omitting the pricing decisions at this stage. The presented problem involves two types of decisions: the frequencies of the services to be offered and the routing of the demands, expressed as itineraries, throughout the service network. A mixed integer mathematical program is considered for that purpose in the interest of operating costs' minimization; a reasonable primary objective for both freight carriers and clients.

In the previous sense, two path-based formulations are examined. One is traditionally concerned with domestic, short distance corridors, while the other extends its scope to incorporate basic service performance measures that can potentially become more pronounced on long-distance corridors. In the first formulation, each service is characterized by its origin, destination, transport mode, capacity and its physical route in the network that is, in a first step, simplified to a direct link. A demand's itinerary, on the other hand, corresponds to the sequence of services used to move the flow of the demand in the network. A procedure is implemented at a pre-processing stage to generate geographically feasible itineraries and eliminate those that do not conform to intermodal specific paths' standards. A multicommodity case is studied, where each commodity is defined by its origin, destination and total demand volume. The problem explicitly considers the service frequency and demand itineraries variables that minimize the cost of operating the services and moving the demand volumes over the itineraries, such that the demands' satisfaction and service capacity constraints are respected.

In the second formulation, on the other hand, the tradeoff between the economic and the service performance objectives is particularly addressed. A service is further defined by a service departure day of the week, limiting the frequency of the long haul services to one service per day. For each commodity, an average service duration to deliver the total demand is computed, so that an approximation of the actual exceeded service duration is penalized in the objective function, alongside the costs minimization. The rest of the previous formulation is carried on, with the exception of the addition of necessary constraints for calculating the service duration differences. Furthermore, since long corridors are specially targeted with this problem, round trips of long haul services are ensured through special constraints; a criteria whose presence has been frequently noted in the industry as essential in offering long distance freight services.

Both formulations are tested using a commercial solver. For the first model, the case of Belgium is considered, based on recent figures of yearly transported freight demands and intermodal terminals' locations. For the second model, however, fictitious demands' data are used inspired by actual European freight corridors. Computational experiments of both cases demonstrate a reasonable behavior of the models. The results of the second case, in specific, highlight the tradeoff between the conflicting objectives at the expense of the service network density and accentuate the importance of an accurate penalty parameters' tuning.

In the next stage to proceed with the target bilevel formulation and in order to increase the realism of the model, a survey will be launched among prospective intermodal clients to conclude about their choice criteria of freight services. The drawn results will be further embedded into an appropriate choice model, potentially combined with some probabilistic choice element and ultimately constituting the basis of the lower-level problem.

The underlying research in this work is conducted in accordance with the project BRAIN-TRAINS, concerned with the future of rail freight intermodality in Belgium and Europe, and funded by the Federal Science Policy according to the contract n. BR/132/A4/ BRAIN-TRAINS.

Horizontal Cooperation in Dial-a-Ride Services

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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, to which a number of service level requirements are linked. The service provider attempts to develop efficient vehicle routes and time schedules, respecting these requirements and the technical constraints of a pickup and delivery problem [5]. A frequent objective is to minimize operational costs subject to full demand satisfaction and side constraints, 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. In light of the ageing population, dial-a-ride systems are gaining importance to complement regular transportation modes. They also fulfill a social role, preventing isolation of vulnerable groups in society.

The current practice consists in that users choose a particular service provider to submit their request. If multiple providers operate in the same area, they solve separate routing problems based on the requests they received. However, research related to freight transportation shows that horizontal cooperation between carriers may allow them to obtain joint operational benefits [3, 6]. The aim of the present research is to determine whether these findings also apply to passenger transportation, which is characterized by tighter quality requirements. Horizontal cooperation may be established in two distinct manners. On the one hand, service providers may exchange requests that are difficult to serve in their own routes. This implies that vehicle routes are optimized from a more global point of view. On the other hand, service providers may achieve additional savings through a reallocation of vehicles among their depots. If reviewing this decision on a daily basis is impracticable, the best allocation can be determined in the medium term based on the distribution of requests.

To account for the presence of several providers, a multi-depot variant of the DARP is adopted [1]. Horizontal cooperation is modeled through the possibility of exchanging requests and/or vehicles among these depots. Computational tests are carried out using a new large neighborhood search (LNS) algorithm, which efficiently solves the problem variant under consideration. Different data sets are used, ranging from artificial benchmark instances to data with real-life characteristics, such as clustered requests. The results show that both types of horizontal cooperation cause considerable reductions in the (joint) distance traveled, as well as in the required fleet size. The magnitude of the operational savings depends on the service level offered [4]. Besides, a pattern can be observed in the choice of which requests are exchanged among the service providers. These results provide support for the creation of an overarching body which collects all user requests in a certain area, after which a globally optimal route planning can be constructed. Anyway, the service providers involved should make clear agreements regarding the allocation of costs and revenues [3].

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Combining acceleration techniques for pricing in a VRP with time windows

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In this study, we investigate a solution methodology for a variant of the VRP with time windows. The cost of each route depends on its overall duration (including waiting times), while the departure time of a vehicle is a decision variable. Furthermore, each route has a maximum permitted duration.

In order to solve this problem with a branch-and-price methodology, we study also the associated pricing problem, an elementary shortest path problem with resource constraints (ESPPRC). Compared to the classical ESPPRC, this variant admits an infinite number of Pareto-optimal states. In order to tackle this, it was shown in [1] that it is possible to represent the total travelling time as a piecewise linear function of the service start time at the depot. Together with this representation, an appropriate label structure and dominance rules are proposed and integrated into an exact bidirectional dynamic programming algorithm [2].

It is possible to implement certain acceleration techniques in the dynamic programming algorithm used to solve the pricing problem. We focus on two of these techniques: decremental state space relaxation (DSSR), introduced in [3], and *ng*-route relaxation, introduced in [4] and [5]. DSSR aims to enforce gradually the constraints on the elementarity of the path, which adversely affect the number of generated and dominated labels. A set of critical nodes is iteratively populated, and elementarity is enforced only on these critical nodes. When using *ng*-route relaxation, a neighbourhood is defined for each vertex. Then, the labels are extended such that, thanks to this neighbourhood structure, it is possible to allow only cycles that are relatively expensive and therefore less likely to appear in the optimal solution.

In this study, we explore several different strategies used to apply these techniques, for example initialization strategies for the critical vertex set in DSSR, or the size of the neighbourhoods for *ng*-route relaxation. We also analyze two ways of combining DSSR and *ng*-route relaxation. The different algorithmic choices are represented as categorical parameters. The categorical parameters, together with the numerical ones, can be tuned with tools for automatic algorithm configuration such as the `irace` package [6].

We discuss how this column generation procedure can be included as a component in the development of a matheuristic based on the idea in [7], which consists in a collaboration scheme between a branch-and-price algorithm, an exact MIP solver, and a metaheuristic.

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A Fast heuristic for the Dial-a-Ride with Transfers

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The Dial-A-Ride Problem (DARP) is an operation research model for on-demand transportation. This system allows elderly and disabled people to move a short distance providing ride requests from an origin to a destination. These demands include hard time constraints (maximum ride times and time windows), while the system must fulfil the maximum route times and capacity constraints related to the fleet of vehicles. The latest evolution in transportation could enable on-demand transportation systems to be more widely and commonly used. The technologies like geo-localization, mobile communication, connected cars and autonomous cars indeed provide new services for a more efficient system in terms of costs and quality of service. This evolution could explain why the DARP is experiencing a resurgence in the operation research literature since the last decade.

Laporte et al. (2007) gives different ways to model the DARP with ILP. However, the complexity of the problem (NP-Hard) and the responsiveness expected for this type of system (there are short time intervals between the transmission of the demands and the rides) forces the problem to be handled through heuristic techniques. One of the main research papers on the DARP is Cordeau et al. (2003). They developed an efficient metaheuristic based on the Tabu Search to solve randomly generated instances which contain between 24 and 144 requests. Dynamic Programming (Psaraftis (1983)) and Variable Neighborhood Search (Healy et al. (1995), Parragh et al. (2010)) are also good techniques to deal with the static problem.

The problem studied in this research allows the vehicles to satisfy a demand with transfers (or *transshipments*). This problem is named the Dial-A-Ride Problem with Transfers (DARPT). Masson et al. (2014) established its formulation for the first time. Here, the locations of the transfer nodes are static. Indeed, the transfer points could be either an origin node or a destination of any demand.

We may refer to the Pickup and Delivery Problem with Transfers (PDPT) for a larger state of the art. For some exacts methods, we may refer to the Cortes et al. (2010), and Rais et al. (2014) papers. However, as stated previously, the exact methods are not well adapted to the DARP (and thus also to the DARPT), only approximate methods are able to solve the problem in time. In this context, Masson et al. (2013) develops a VNS and solves big instances with almost 200 requests. Shang et al. (1996) proposes an insertion heuristic where each pick-up and delivery nodes could be a transfer point. The transshipments are only allowed for the demands which couldn't be inserted. This algorithm is adapted to the dynamic case by Thangiah et al. (2007).

In this work, we are solving the DARP and the DARPT with dynamic transfer points by two randomized insertion heuristics into a Monte Carlo Process based on Deleplanque et al. (2013). We optimize an objective function with a mixed QoS/Economical Cost performance criterion. The validity of each insertion is mainly tested by the propagation of time constraints. The precedence constraints due to the transfers are included in this process. Their locations are located dynamically according to the shortest path joining the routes of the two vehicles involved. We present models of the DARP and the DARPT. Then, we describe and test our heuristics which propagate the time constraints for both problems. Finally, we present some experimental results obtained from our heuristics.

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New Test for the Assessment of some MCDA Methods

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Abstract:Many of MCDA methods was used to solve real-life decision problems concerning the problematic of choice, ranking and sorting. However, as that the comparative study between these methods is meaningless because the contexts in which these methods work are relatively different, it would be wise to study separately the performance of each method. On this latter plane, it should be noted that very few research works were established in the literature.
In this paper, we propose a new test to evaluate the multicriteria methods. This test can help the decision maker to choose the best solution to his decision problem among several best solutions.

Judging a multicriteria method on mathematical aspects (properties) such that the independence of the irrelevant alternative, the transitivity..., can lose the most non-expert users in the field of multicriteria decision aiding. In fact, we must always attract their attention to the fact that the non-verification of certain mathematical properties do not necessarily accuse the reliability of the used method. However they must be informed of the limitations following the use of each method.
Often the non-verification of some properties is an inevitable consequence of the ranking procedure characterizing the method, in particular, the case of Electre, Prométhée, AHP, ..., etc. To this effect, it would be wiser to evaluate the performance of the method according to the practical results and not on theoretical aspects.
When we can get the unanimity of the methods (i.e. when several methods define the same good solution for the same decision problem), the problem of the best alternative definition A^* is practically solved. However, In the opposite case, we must question ourselves about which one of the best solutions obtained by the different methods is the right one.
On this basis a new test is developed. It allows to choose the best solution among several good solutions established by deferent methods for the same decision problem.
The mathematical formula used is characterized by a remarkable flexibility in the selection of the best alternative. indeed, there is no additional parameter involved in the computation (threshold, reference point,..., etc), also, the ratio established between the performances allow to avoid the normalization which can cause a serious stability problem. On the other hand, it makes exploitable the importance of variance between the performances.
On different examples, we can show how this aggregation can privilege a equilibrant alternative compared to another having certain evaluations very weak and some qualities elsewhere, it can also weaken the effect of the exaggerated compensation in the presence of important conflicts between the criteria of two different alternatives.
In addition, this formula involves a very small degree of intransitivity which depends,

mainly, on the number of methods used. In order to study the percentage of intransitivity in the existence of more than two good solutions, a statistical study was established. Using a data randomly generated we counted the number of instances comprising at least one intransitive relation between the alternatives, this experiment was carried out by varying each time the number of alternatives and criteria, each case contains 1000 numerical examples.

Key words: MCDA methods, the series of tests, Independence property, Transitivity property, new test

An extension of PROMETHEE II to hierarchical clustering

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PROMETHEE [3] is a family of Multiple Criteria Decision Aid Methods that has been developed at the Université libre de Bruxelles since 1982. It is based on pairwise comparisons of the alternatives and allows ranking them according to a complete or a partial ranking (based of positive, negative and net flow scores). GAIA offers complementary visual tools to help decision makers in structuring and describing their decision problems. A recent literature review [2] has identified more than 200 applications of these methods in finance, health care, environmental management, transport, etc. These have been facilitated by the existence of user-friendly software like PROMCALC, DECISION LAB 2000, VISUAL PROMETHEE or D-SIGHT [4][1][7].

Classification is a major topic in data mining. It refers to the division of a data set into different groups. These can be defined a priori (in case of supervised learning) or during the course of the process (in case of unsupervised learning). Methods belonging to the latter family are also called clustering methods. Among traditional approaches, one may mention the K-means [6] and Hierarchical clustering [10] algorithms. The latter is based on the successive division of the data set into subsets (based on a criterion related to the heterogeneity of the remaining groups). The procedure is repeated until the desired number of clusters is reached.

The method developed in this presentation belongs to the recent field of Multicriteria Clustering [8] i.e. the identification of clusters in a multicriteria context. A distinctive feature of such approaches is the explicit consideration of the asymmetric nature of multicriteria preference relations leading to the identification of (complete or partial) relations between the clusters.

Extensions of PROMETHEE to clustering have been recently proposed. Among them, P2CLUST [5] is based on the K-means principle. Each cluster is characterized by a central profile. Then, alternatives are successively compared to the different central profiles and are assigned to the cluster with the closest net flow score. Once the assignment has been completed, the central profiles are updated. The process is then repeated until the class membership no longer changes. More recently, another extension, called PCLUST [9], has been presented in order to address the problem of interval clustering (i.e. clusters are ranked according to a partial order).

In this presentation, we develop a new extension of PROMETHEE to hierarchical clustering. This is based on a new property of the net flow scores that allows dividing data sets (and subgroups) in an appropriate way. We assess the performances of this new method both on the quality of the obtained partitions and execution time. Comparisons with

P2CLUST are performed and shows the added value of this deterministic approach.

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Multicriteria-enriched representations of evaluation table using the PROMETHEE methods

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Most strategic decision problems involve the simultaneous optimisation of several conflicting criteria. Generally, the first step to solve such problems is to identify the set of alternatives and the criteria they will be evaluated on, leading to the construction of an evaluation table. Of course, there are numerous ways to build such a table. For a problem of n alternatives and m criteria, there are $n! \cdot m!$ possibilities of representation. However, from a multicriteria point of view some of them can be more interesting than the others. In this work, we investigate how to represent the evaluation tables in order to display as much multicriteria information as possible and we will focus on the PROMETHEE and GAIA methods. The extracted information will serve to build tables to convey additional characteristics of the problem. In most cases, these representations will focus on gathering similar alternatives and rearranging the criteria such that their strong and weak characteristics appear more clearly. Furthermore, out of the many possibilities that stem from using the PROMETHEE methodology, we will identify those that yield the most relevant results. In order to evaluate the properties of these PROMETHEE-based representations, an indicator will be defined that uses only ordinal information of the values contained in a given table. This measure will also serve as a fitness function for a genetic algorithm that will find good – if not the best – tables. These will allow to draw comparisons with PROMETHEE-based representations. The results obtained show that multicriteria-enriched tables, while giving additional information, still hold interesting ordinal properties.

HPC ranking big performance tableaux with multiple incommensurable criteria

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In the context of the ongoing GDRI-Algodec "Algorithmic Decision Theory", supported o.a. by the CNRS (France) and the FNR (Luxembourg), we develop multicriteria ranking algorithms for large sets of potential decision alternatives: up to several thousand of alternatives evaluated on multiple incommensurable ordinal performance criteria.

This research is motivated by the development of a visualization tool - a **heat map** - for performance tableaux showing the decision alternatives linearly ordered form the best to the worst, and the individual performances colored by quantiles equivalence classes [2, 1].

By using Python3.5 multiprocessing resources and the Digraph3 multicriteria software library [3], it is possible, on the UL HPC cluster [4], and more specifically on the gaia-80 machine with 120 single threaded cores and a CPU memory of 1.5 TB, to linearly rank (without ties) in less than an hour a huge set of 250000 alternatives evaluated on 21 performance criteria by balancing economic, ecological and societal decision objectives.

Data input is, on the one side, a 250000x21 performance tableau of size 825 MB, and on the other side, a theoretical preference space consisting of 62 000 000 000 (billions) of pairwise outranking comparisons [5, 6].

A "small" set of 1000 decision alternatives, in a similar setting, may thus be ranked typically in less than 5 seconds.

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Advanced Analytics to Capture the Full Value of Demand Response and Energy Flexibility in Industrial Sites

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Nowadays, with the increasing volatility of electricity prices and the growing importance of Demand Response (DR) programs, there are more and more incentives for energy-intensive industrial sites to be flexible in terms of electricity consumption and generation. However, the complexity of these large industrial plants, having to deal with many interconnected processes, multiple energy flows, integrated CHP and renewable electricity generation, as well as many technical constraints is often a barrier to fully leverage the different energy flexibility levers of the plant.

In this talk, we propose an advanced analytics approach to help industrial sites capture the full value of their energy flexibility. Thanks to integrated mathematical models of the full energy ecosystem of the plant which will include the constraints, the flexibility of the different processes and their complex interdependencies; it is now possible to predict the total cost impact of different energy management decisions and also to optimize these decisions with respect to electricity price and demand response incentives.

We have developed a framework based on OscaR to build integrated mathematical models of industrial plants. This framework works following a network based principle. That is, an industrial process is decomposed as a set of processing steps (the nodes in our network) with flows of products transiting between them (the edges). The nodes model constraints and the edges model variables. The complete model is built by traversing the network. Thanks to OscaR, different methods can be combined to define the best model(s) of each process. For example, a continuous process will often be better represented using a mathematical programming approach whereas for a batch process it will often be better to use constraint programming. In this way, we have a powerful framework that allows us to accurately represent the unique situation of each industrial plant.

Based on this optimization model, key decisions can be taken over different time horizons:

- ◇ Long term: investment in energy flexibility assets and choice of energy contract
- ◇ Mid term: choice of flexibility products
- ◇ Day-ahead: scheduling of electricity load and internal production
- ◇ Real-time: imbalance and activation management

We will illustrate this approach on an example in the pulp and paper industry.

Microgrid becomes more and more an opportunity. How advanced analytics can help in the optimal design and operation of eco-zoning.

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Nowadays, industries have observed an increase of their electricity bill mainly due to high taxes and network charges. As a result, industries have more and more the incentive to investigate new closer power generation solutions in order to produce locally and avoid extra charges for using the network. As a matter of facts, renewables technologies become more affordable and push industries for investing into decentralized power system. Especially, industries will co-invest in order to leverage best their electricity produced, as the extra electricity is less valued on the market. This solution is commonly called a microgrid, and is a set of loads and generators in the same local area than can be operated independently or in conjunction with the electrical grid.

Microgrids bring many competitive advantages compared with the standard electrical grid such as higher reliability in case of blackouts, financial aid with green certificates and last but not least, an electricity cost reduction linked to exemption of network charges, taxes and absence of intermediate, due to a local electricity production and consumption, and to a constant reduction in these technologies investment cost. The notion of microgrid is even more attractive in an industrial park with different loads, that can sometimes be complementary, with a common interest of investing in an eco-zoning.

Nevertheless, main challenges remain in dimensioning this microgrid and in operating it daily in an optimal way for the community. The aim of the lecture is to present our advanced analytics approach to help industrial parks investing in microgrids. The solution proposed allows firstly to optimally select the technologies and the dimension of a microgrid and secondly to discuss different methods for the daily allocation of the electricity produced and costs between the participating members.

Optimal dimensioning and technologies selection

Based on the electricity production profile of different technologies, on the different consumption profiles of the microgrid's participants and on the return on investment desired by investors, a mixed integer programming model is solved to dimension and orient the investment trough adequate technologies. This mathematical model considers both OPEX and CAPEX information in their computation.

Optimal electricity and cost allocation

Once the investment has been completed, different methods of electricity allocation within the microgrid's partners can be put in place, such as a proportional repartition based on the electricity consumption or a repartition based on actual electricity price paid by each member. Both approaches will be discussed considering their impacts on the objectives and the different risks occurred such as favoritism or unequal risk sharing.

This presentation will explain how such current renewable energy problematic can be modeled via mathematical approaches and how it enables to quantify both advantages and constraints aiming to help taking the best strategic and operational decisions.

Forward-Checking Filtering for Nested Cardinality Constraints: Application to an Energy Cost-Aware Production Planning Problem for Tissue Manufacturing

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Renewable energy is an increasing part of the European electricity market, adding volatility in the day by day prices [4]. Response to electricity price fluctuations becomes increasingly important for industries with high energy demands. Consumer tissue manufacturing (toilet paper, kitchen rolls, facial tissues) is such an industry. Its production process is flexible enough to leverage partial planning reorganization allowing to reduce electricity consumption. The considered industry has a production planning considering processes from paper pulp mixing to conversion of paper rolls into final products. The production of paper rolls from paper pulp is the process requiring the larger amount of energy in the whole production plan. The idea is to shift the production of the tissues (rolls) requiring more energy when electricity prices (forecasts) are lower. As production plans are subject to many constraints, not every reorganization is possible. An important constraint is the order book that translates into hard production deadlines. When a change of paper type occurs in the production, a calibration of the machines is needed and a transition phase during which the paper has a lower quality happens. To express this disadvantage, each transition from one paper type to another is associated to a transition cost. The reorganization of the production plan should therefore optimize both energy costs and transition costs.

A Constraint Programming (CP) model to enforce the due dates can be encoded with p Global Cardinality Constraints (GCC) [2]; one for each of the p prefixes of the production variable array. This decomposition into separate GCC's hinders propagation and should rather be modeled using the global `nested_gcc` constraint introduced by Zanarini and Pesant [5]. Unfortunately, as stated in [3], it is well known that the GAC propagation does not always pay off in practice for cardinality constraints when compared to lighter Forward-Checking (FWC) algorithms. We introduce a preprocessing step to tighten the cardinality bounds of the GCC's potentially strengthening the pruning of the individual FWC filterings.

The preprocessing step starts from initial bounds and allow to compute a new set of bounds allowing more pruning. The bounds corresponds to minimal and maximal number of times values can occur on different ranges. This preprocessing step contains three main parts. First, we perform per-value deduction: for each value, from the initial bounds, we can deduce new bounds on neighboring variables. The second step allows to do inter-value deductions: for each value, regarding bounds on other values occuring on the same range, we can deduce new tighter bounds. Finally, we can reduce our set of tighter bounds to the unique smallest set of bounds that contains all the useful information initially specified.

This final set of bounds obtained is always a subset of the times at which a lower or upper bound was originally given.

We further improve the FWC propagation procedure with a global algorithm reducing the amortized computation cost to $\mathcal{O}(log(p))$ instead of $\mathcal{O}(p)$. We describe an energy cost-aware CP model for tissue manufacturing production planning including the `nested_gcc`. Our experiments on real historical data illustrates the scalability of the approach using a Large Neighborhood Search (LNS). Results show that the precomputation steps effectively allow to perform additional pruning compared to initial bounds. This additional pruning allows to greatly reduce the time needed to solve instances. However, the new `nested_gcc` $\mathcal{O}(\log(p))$ propagator shows resolution times similar to the multiple GCC's $\mathcal{O}(p)$ propagator. Indeed, the historical instances are not dense enough in terms of deadlines and stock constraint to observe a difference between linear and logarithmic propagation times. However, on personal instances not related to the paper planning problem, the new propagator is faster. Our implementations are available in the open source solver OscaR [1].

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Advancing OR/MS education using case studies and educational games

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A major challenge in teaching Operations Research Management Science (OR/MS) courses, especially to students for whom OR/MS is not the primary field of study (e.g., MBA students), is to motivate them to recognize the need for OR/MS tools in decision making. Many OR textbooks fail to motivate students to formulate, solve, and use optimization models. The main reason for this is that the textbook exercises to practice optimization modeling almost always take the form of an assignment that includes text that fully defines a fictional, small business problem in which the objective function and constraints are clearly described. Innovative teaching approaches like the use of case studies and educational games have proven to increase both students' interest and teaching effectiveness, but instructors often have difficulty finding suitable, relevant, and topical cases or educational games. The objective of this contribution is threefold. First, I present some concrete examples of self-developed classroom games and cases that were published in the open-access journal INFORMS Transactions on Education (ITE). Second, I will share my experiences with submitting articles to ITE in order to inspire authors who want to publish their work in ITE. Third, from my role as editor, I will provide suggestions and guidelines for publishing cases and educational games in ITE.

Impact of plant configuration on capital costs and asset efficiency: study of a chemical blending plant

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Introduction

Increasing pressure on plant performance forces production companies nowadays to take appropriate decisions on the strategic and tactical level. In our research we focus on decisions on plant design and production strategies and their mutual influence, in particular for chemical batch plants. The design of such plants addresses plant configuration (i.e. number, size and connectivity of equipment) and the related batch sizes of the different manufactured products. The aim of these design problems, generally formulated as MINLP models, is mostly to minimise only capital costs [1]. Production strategies, on the other hand, define how plants should be operated (e.g. by dedicating products to equipment) and are normally translated into objectives for plant performance indicators such as the SCOR performance attributes asset efficiency, cost effectiveness, reliability, responsiveness and flexibility [2].

In this paper, we focus on the design of multiproduct chemical blending plants, which are typically equipped with blending tanks, pipelines and intermediate storage. We introduce the concept of parallel production lines, i.e. specific lines that can be dedicated to particular products or product families, and investigate their impact on the objective function. Concerning this objective function, we consider capital costs but we also include operational (setup) costs and asset efficiency and study their influence on the plant configuration.

Chemical blending plants

Chemical blending is classified as a batch process and consists typically of one or more bottleneck stages. In general, these stages involve longer processing times and/or capital intensive equipment. Non-optimal use of bottleneck equipment may slow down the entire process. As discussed in literature [3], introducing parallel equipment per stage and intermediate storage between stages aim at reducing the dominance of these bottlenecks. In practice, we observe another design option that is frequently used in chemical plants, namely the installation of parallel production lines [4]. Each production line consists of all stages and operates independently but simultaneously with the other line(s) in single product campaign mode. However, products (product families) can run over different production lines.

We propose an extension of the existing formulations with parallel production lines and determine the optimal assignment of products to these lines together with the number and size of equipment. At first, the objective is to minimise only capital costs while satisfying design, horizon and demand constraints. Then we add operational setup costs and asset-related opportunity costs. The opportunity costs represent a penalisation for leaving installed capacity unused. We notice indeed a mutual influence between these costs and the plant configuration. Finally, we include short term intermediate storage per production line and investigate the effect on the aforementioned cost components.

An example of a lubricant production plant is used to demonstrate the applicability of our model.

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Buyer-Supplier Relationship and Resiliency from Supply Disruptions

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Whereas firms aim at optimizing their expected profits, they also want to minimize the risk to face a result that is largely worse than the expected one. Especially, as supply chains become increasingly complex and global, buyers rely on many suppliers on which they often have a limited visibility and/or control. Moreover, as disruptive events (e.g. strikes, political instability, terrorism...) occur at a faster rate than before, these buyers get exposed to a higher level of risk of supply disruption. Especially, natural disasters hit global supply chains more frequently and more intensively than ever. As a consequence, buying firms have to take such supply disruption risk into consideration to avoid an unlikely but dramatic impact on their profits.

Over the years, the buyer-supplier relationship have received a huge amount of attention. Indeed, although in the past the focus was mostly on supply price, many authors have documented that strong ties between a buyer and its suppliers could lead to higher profits. This had been pushed to the extreme as buyers started to contract with single sources of supply for many different components. However, some recent natural catastrophes discouraged buyers to rely on too few suppliers since a single component missing can result in an idle production. While it sounds intuitive that a weaker buyer-supplier relationship would enable a buyer to switch more easily of supplier, some examples testimony that some dimensions of a strong buyer-supplier relationship can improve the resiliency of a firm to a supply disruption. Indeed, when the fire declared at a Philips plant, the visibility that Nokia had on Philips and their efficient communication enabled Nokia to discover the problem early and to secure the remaining production to the detriment of Ericsson, another major customer of Philips. Also collaboration and joint problem solving enabled Aisin Seiki to resume production only 2 days after that a fire broke up at one of its plant, rather than a few weeks as initially expected. This was made possible by Toyota, which procured 99% of a particular component at Aisin Seiki. Therefore, to avoid a production halt of weeks, Toyota has gathered several of its partners to solve the problem at Aisin Seiki (Nishiguchi and Beaudet, 1998). In 2011, the same experience has been observed at Renesas, a firm producing about 10% of the micro-controllers for automobiles worldwide. Fearing dramatic consequences for their own production, Japanese car-makers decided to send their workers to resume operations as fast as possible (Okazumi et al., 2012). Unfortunately, there is so far no literature documenting how the buyer-supplier relationship can affect the resiliency of a buyer to an unpredictable supply disruption.

The objective of this paper is to fill this gap. For this, we first apply an event study methodology to a database of 204 unpredictable supply disruptions. This empirical technique enables us to isolate the part of the stock returns that can be associated to the supply disruption considered (i.e. the abnormal returns). Our database only contains supply disruptions caused either by the 2011 Japan quake and/or by the flooding in Thailand the same year. We selected these two events because they are the main recent natural disasters. Okazumi et al. (2012) notice that 2011 has been the costliest year ever in terms of natural disasters, with a 50% increase from the previous record of 2005. Moreover some major industries (e.g. electronics, automotive...) are concentrated in this area. For example, Thailand accounts for 43% of the world hard disk drive production. Therefore the floods have provoked supply disruptions all over the world.

In an earlier paper, Hendricks and Singhal (2005b) have discovered that stock returns are affected on average during one year after a supply disruption. In this paper, we first investigate whether our database confirms this result and we intend to give a more accurate estimation of the necessary length of time for firms to recover from a supply disruption. Then, we regress these abnormal returns of each firm over data related to the different dimensions of a buyer-supplier relationship. We obtain this data from interviews, questionnaires, as well as from Capital IQ. This permits us to estimate whether the abnormal returns are partly explained by the type of buyer-supplier relationship, and what is the impact of each dimension of the buyer-supplier relationship on the resiliency of a firm.

In the financial literature, the well-known property of market efficiency assumes that information is reflected immediately in the stock returns. However, in the case of a supply disruption, its impact should be felt a certain while after the event, as both the buyer and the supplier might have some inventories to keep production on. Moreover, the information might not arrive immediately, and might even arrive once the problem is gone. Therefore it is logical that the impact of a supply disruption would not realize completely the day of the event at the supplier. Moreover, we anticipate the stock returns of buying firms to be strongly impacted at the event date, either because the buyer could also have been hit by the event, or because of the uncertainty of the investors. Consequently, we will mostly focus on longer term impact.

Optimal inventory management in case of fluctuating market conditions

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Abstract

A cost-effective inventory management is crucial in the highly competitive environment in which companies operate today. Traditionally, the purchase and inventory cost as well as the demand are assumed to be constant along the replenishment cycle. In this work, we relaxed these assumptions and the costs are subject to certain market tendencies. Assuming Markovian demand and price fluctuations, the optimal ordering strategy is determined by a Markov decision process (MDP) approach.

Usually, the analysis of inventory systems is carried out without considering the impact of price fluctuations. Most studies that attempt to capture price evolutions such as inflation, are formulated in a static environment where demand is assumed to be constant over time. This study most closely relates to De Cuypere et al. [1], in which a discrete-time Markovian model with stochastic demand and market price fluctuations is proposed. In contrast to [1] which considers a price model that fluctuates around a long-term average, our model assumes two distinct market conditions: the price or cost can either be subject to a downward trend or an upward trend. This way, we can incorporate factors such as political and regulatory changes, new technology or changing market conditions. When the price level follows the upward trend, the probability of a price increase α is higher than the probability of a price decrease β. In other words, the price is expected to increase. The opposite is true in case of a downward trend (γ is smaller than λ, respectively denoting the probability of a price increase and price decrease for a downward trend). The probability of a transition between the two trends depends on the price level as well as on the market conditions. A transition from an upward trend to a downward trend is denoted by δ, while the opposite transition is denoted by ϵ. For each state, there are six possible states to which the market can move to. In an upward trend, the price at the next time step may rise, fall or stay the same and is possibly accompanied with a transition to the other market trend. The dependence on the price level is accomplished by the introduction of an extra parameter υ, which denotes the rate at which ϵ or δ decrease.

Besides price fluctuations, demand fluctuations are also considered to influence the inventory system of a product. The inter-arrival time between successive demands is modelled by a negative binomially distribution with parameters p and r, which respectively denote

the success probability and the number of stages. This allows us to investigate the impact of different variabilities and its use is justified by empirical evidence [2]. The maximum order quantity is equal to the inventory capacity C. With a low inventory capacity, one can less benefit from a future price increase and thus the capacity can influence the order policy as well. To summarize, the modelling of the stochastic demand essentially comes down to a Markov chain of rC states.

By combining the two sub-models, we obtain a three-dimensional discrete-time Markov chain. $S_{j,k,l}$ represents for instance the state with an inventory of $C-j$ products, price level k and demand stage l. To determine an optimal ordering policy, we take immediate and future costs into account. The total cost function includes the inventory cost, purchase cost and fixed order cost. By introducing a fictional inventory level of -1 in the model, we can easily extend the model and take the cost of lost sales into account as well. Markov decision processes can be solved with the aid of linear programming or dynamic programming [3]. In this study, the latter approach is chosen and the 'MDP Toolbox' in Matlab is used to determine the optimal policies.

The aim of this study is to investigate the influence of the market conditions, inflation rate, variability, etc. on the optimal order policy. The optimal order policies for each states are compared with traditional policies such as the EOQ model adjusted for inflation. Preliminary results already indicate that that a relative small change in the parameters of the market conditions, can lead to quite different optimal policies. This stresses the importance of customizing the order policy to the market tendency of each material separately.

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A convex reformulation for the cyclic inventory routing problem

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Introduction

Recently, supply chain managers of up- and downstream stages of the supply chain are getting more and more convinced of the interest of cooperating and integrating their businesses. The synchronization of activities throughout the whole supply chain enhances its overall performance and competitiveness. Vendor managed inventory (VMI) is a frequently used business model in this context. In a VMI-system the supplier is responsible for managing the inventory of his customers. The combined inventory management and routing problem that arises in this context, is called the Inventory Routing Problem (IRP). Generally, the IRP is concerned with the distribution of products from one or more facilities to one or more customers over a given planning horizon. For this purpose the supplier has one or more vehicles at his disposal. We consider a cyclic variant of the general IRP, the Single-Vehicle Cyclic Inventory Routing Problem (SV-CIRP). The goal is to find a cyclic distribution plan for a set of customers. An important aspect in solving the problem is that it is not mandatory to visit every customer. Instead, a reward is collected for every customer that is visited. The objective is thus to simultaneously minimize transportation and inventory costs and maximize the collected rewards.

Modeling approach

Reformulation

The latest known model that was presented to solve the SV-CIRP is Zhong and Aghezzaf [3]. The continuous relaxation of this model has a non-convex objective function and is optimized over a convex set. Starting from this model we introduced new variables in order to write the objective function in function of linear and quadratic terms. We showed that the new objective function was non-convex, but differentiable. Modelling the problem in such a way caused the continuous relaxation to be a optimization of a non-convex function over a non-convex set. We were able to show that when the problem was solved over the convex hull of the non-convex set, the solution was also a valid solution for the non-convex set. Finally the quadratic terms in the objective function could be linearized using McCormick linearizations [2]. The final result was that the continuous relaxation of our reformulation was a convex problem on which traditional branch-and-bound procedures could be applied.

Solution method

A major complication in solving the SV-CIRP is the complexity of the problem. Even for discrete points in the time domain the problem is NP-hard, as it envelops the Travelling Salesman Problem (TSP). When the problem is solved globally, we may expect it to be even more complex. We found that it was essential to restrict the range of the complicating variable as much as possible. For this purpose we used the continuous relaxation of the convex problem which is a lower bound on the integer problem and because it is convex, it is sure that there are no better solutions outside the bounds it provides in the time domain. Whenever an integer solution was found in the branch-and-bound procedure with a lower cost than the current best solution, bounds were calculated in the time domain. These bounds were then added as constraints when the branch-and-bound continued.

Results and conclusion

To validate our model and compare its performance to the existing solution methods, we set up an experiment using benchmark instances from literature. These instances are available on the website http://users.ugent.be/ wlefever/. Results showed that our reformulation outperformed the currect exact solution methods and matched up to the heuristics in literature. We were able to prove optimality for 22 instances and found better solutions for 23 other instances.

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Analyzing the impact of coalition characteristics on the performance of carrier collaborations

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Severe competition in global markets and the heightened expectations of customers have caused profit margins of transport companies to shrink. In order to survive under the ever increasing pressure to operate more efficiently, they are obliged to adopt a collaborative focus. Companies operating at the same level of the supply chain may cooperate horizontally to increase their productivity, improve their service level and enhance their market position [1]. Although transport companies become increasingly aware of the inevitable character of collaboration, surveys report failure rates from 50 to 70 percent for starting strategic partnerships [2]. Because every partner of a horizontal cooperation still remains independent, the risk of opportunism remains real. Besides that, the success of achieving collaborative benefits strongly depends on the degree of fit between cooperation participants [3][4]. Similar or complementary strategic orientations, managerial practices, organizational characteristics and partnership goals could significantly influence collaborative performance [5][6]. While a growing body of theoretical research acknowledges the importance of partner characteristics, it is not yet analyzed how the structure of a cooperation is related to the performance of a carrier alliance. The main contribution of our research is thus to provide practical recommendations on which partnership structures may provide the highest collaborative benefits.

Based on the literature review described in [7], the impact of coalition characteristics on collaborative performance will be investigated in an order sharing context. In the majority of carrier alliances customer orders from all participating carriers are combined and collected in a central pool and efficient route schemes are set up for all requests simultaneously using appropriate vehicle routing techniques, a collaboration approach that may be labeled joint route planning. In this way, scale economies, in terms of reduced travel distance, empty vehicle movements and number of required trucks, could be obtained by merging the distribution regions of all collaboration partners [8]. Since existing studies mainly focus on demonstrating the benefits associated with joint route planning, an analysis of the influence of cooperation structure on partnership performance could provide useful insights for transportation companies considering collaboration.

A first contribution of our work is the development of a formal mathematical formulation for the joint route planning problem. Second, the solution approach used to solve the problem, originally developed by [9], is slightly modified for efficiency purposes. Third, as proven by the recent increase in research on rich vehicle routing problems, consideration of practical constraints and applications related to vehicle routing becomes relevant in today's complex environment. For this reason, the novelty of our research lies in the application and analysis of an existing routing problem in a practical real-world context with the aim of providing guidelines to practitioners. More specifically, the main contribution is to provide insight in the impact of coalition characteristics on the collaborative profit level of carrier alliances using the approved statistical technique experimental design.

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Multi-drop vehicle routing problem with safety constraints

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Transportation companies often combine cargo delivery to multiple customers. This enables transporters to reduce the number of vehicles and to transport full truck loads as much as possible. Transporters need to deliver the goods to the right place within a certain time window, in a cost-effective way and without potential damage to the vehicle, to the cargo itself or to other road users. Combining the cargo for different customers in one vehicle is an important measure to help them meet all these requirements.

However, problems combining cargo for multiple customers are subject to multi-drop constraints, which prevent additional cargo handling at drop-off points. Such constraints minimize the potential for loading scheme optimization, due to the fact that they require taking into account the unloading sequence.

While the vehicle routing problem is one of the most academically studied combinatorial optimization problems, the problem of dynamic cargo stability has never been addressed via a decision support-based approach. Loading scheme safety is traditionally appraised by rules of thumb, both by the carrier and authorities.

We propose a decomposition-based approach for solving the combined problem, minimizing both route cost and loading scheme cost. Only solutions respecting cargo security constraints are considered. Loading scheme costs are determined by additional securing methods required for safety. Datasets have been generated along with benchmark results obtained by the algorithm.

Keywords: vehicle routing, container loading, decomposition, sequential loading, cargo safety

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Horizontal co-operation and courier companies: a clustered approach

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Problem outline

Courier companies are specialised in delivering relatively small packages to a large number of customers. This gives rise to a large-scale operational problem that is often handled by dividing the distribution area in *clusters* (also called *zones*), e.g., based on postal codes. In this way, the routes for the delivery vehicles can be constructed as a sequence of clusters. By decoupling the inter and intra cluster routes, the complexity of the problem might decrease significantly. The underlying problem to be solved, is known as the *Clustered Vehicle Routing Problem (CluVRP)*.

In this research, the CluVRP is extended by considering a collaborative environment in which multiple partners (courier companies) join forces in a so-called *horizontal co-operation*. By allowing the exchange of clusters to a partner that can fulfil the delivery requests contained in it more efficiently, the collaboration of courier companies might be able to reduce the overall logistic cost.

Solution approach

At coalition level, a master problem aims at minimising the total logistic cost of the coalition as a whole by allocating each cluster to a partner. This global logistic cost is determined as sum of the routing cost over all collaborating partners, for a given allocation of clusters.

Starting from the current solution (initially this will be the stand-alone scenario in which each partner visits its own clusters), the master problem will suggest a potential profitable *exchange of clusters*. For each partner that is affected by this move, the slave problem is solved. Here, the individual partner should define the amount of money he is willing to pay / wants to receive in order to make this move acceptable. If the partners involved agree, based on these financial implications, the move is executed and a new potential move is suggested by the master problem. This is done until no feasible move can found, or the partners are no longer willing to exchange clusters. It can be noticed that it is not imperative that the solution procedure for the individual slave problems, is the same for different partners. Companies might not be willing to exchange certain clusters for strategic reasons, impose a certain profit margin,. . .

A small example for a two-partner co-operation with six clusters is shown in Figure 1. In the initial situation, both courier companies work independently. Because of geographical

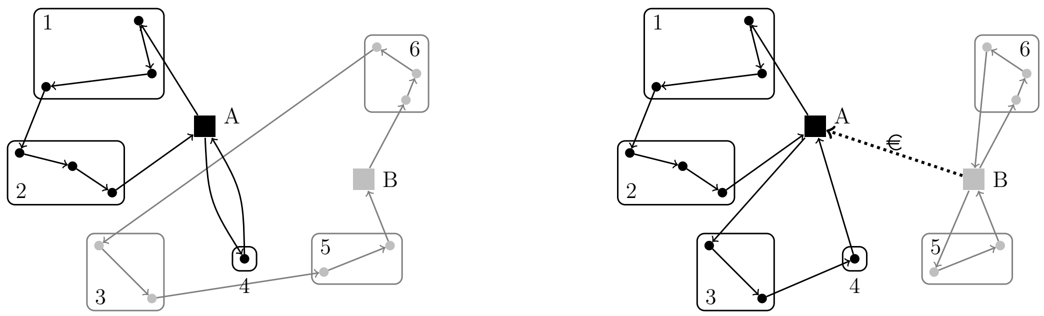

Figure 1: exchange move for one cluster in the CluVRP with horizontal co-operation.

overlap, the master problem suggests that it might be profitable to relocate cluster 3 from partner B (the grey company) towards partner A (the black company). This move implies an increase in routing cost for A. Therefore, A will only accept this exchange, if it receives a compensation fee from B. The height of this fee is determined by the slave problem for partner A, but is expected to be at least the marginal cost for including cluster 3 in its operational plan. B, on the other hand, might be willing to pay a certain fee to A, as the proposed exchange move results in a decreased routing cost for B. The willingness of B to pay a fee to A is determined by the slave problem for partner B. If B is willing to pay the fee that was requested by A, the exchange move is executed. This procedure is continued iteratively, until no exchange move can be found by the master problem that is accepted by the individual partners. Because of the integrated master-slave approach, en the inclusion of compensation fees while performing the optimisation procedure, a feasible operational plan is constructed that is accepted by all individual partners. Furthermore, we ensure that the total logistic cost is allocated to the partners implicitly, without using an external cost allocation mechanism, that divides the total coalition cost, after the optimisation procedure.

On toll-setter's gain when network user faces uncetainty

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Introduction

Public-Private partnership and private investment are becoming more popular than ever in infrastructure projects. Typically these projects employ build-operate-transfer model. Here the investing company enters in a contract with government to build a road/highway. In return, company is allowed to collect tolls for an agreed period of time before the transfer of ownership to government. A key element to the success of this model is the revenue generated from tolls. The investor company's main objective is to maximize the revenue from tolls. In a full information scenario where users are fully aware of the costs, typically it is assumed that users will try to minimize their total cost of travel. However, in practice it is never the case that a user will have a complete certainty on costs/times of travel. In other words there is almost always uncertainty in the network. In such a case, the task of toll setter becomes even more complicated as he now has to anticipate the network user behavior in the presence of uncertainty.

Of course, toll setter would want to make use of this uncertainty to increase his profits. In this work we address the question: to what extent toll setting company can or cannot reap the benefits of the underlying network uncertainty to increase his revenues? The gain a toll-setter can make from network user uncertainty depends on many different factors: the level of uncertainty faced by the user, user's perception of uncertainty and decision-making under uncertainty, level and structure of toll-setter's ownership of the network, and proportions of different types of users. In order to understand the impact of these factors on toll-setter revenue, there are two key elements to consider from the modeling point of view. First, how to model the underlying network uncertainty? Second, how to model the route choice behavior of network users in the presence of uncertainty? In this work we model the user uncertainty by uncertainty sets (robust optimization framework) and model the route choices using popular robustness measures. To quantify the gain of the investor company due to uncertainty we measure the toll-setter revenue from each user type relative to his revenue when there is no uncertainty, we call this *uncertainty gain*.

We use the bi-level framework provided by Labbé et al. (1998) for deterministic toll-pricing: given is a network $N = (V, A)$, where an authority owns a subset of arcs and imposes tolls on them. The authority, usually referred to as *leader or upper level decision maker*, wants to maximize his/her revenue from the tolls. The network users, usually referred to as *followers or lower level decision makers* aims to minimize their costs by traveling on the minimum cost paths. Apart from tolls, users also pay a fixed cost when traveling on arcs.

We consider the situation when the level of variability (measured in terms of index of dispersion) on each arc is bounded (in a single commodity setting in both congested and uncongested networks). More specifically we assume that on each arc a the variance-to-mean ratio is bounded from above by a fixed constant κ. Our primary aim is to understand the gain of toll-setter with respect to κ under three different user behaviors. Among our secondary objectives we (1) initiate the study of selfish routing when network users are regret minimizers and pessimists, (2) initiate the algorithmic study of robust toll pricing.

Contributions

The primary contribution of our work is the use of robust optimization methodology to understand the impact of network uncertainties on the toll-setter revenues.

- ◇ We show that when costs on arcs are uncorrelated, cost-minimizers are likely to spend less compared to regret-minimizers and pessimists.
- ◇ We study the existence of pure strategy Nash equilibria in congested case. We show the existence of equilibrium routing in case of pessimists and cost-minimizers. In case of regret-minimizers we show the existence of equilibria in the special case of affine costs and series-parallel networks.
- ◇ We formulate the toll-setter problem as a bilevel optimization problem in both congested and uncongested networks, extending the model of Labbé et al. to uncertain costs case.
- ◇ We analyze uncertainty gain (UG) of toll-setter assuming three types of network users (*pessimists, regret-minimizers, cost-minimizers*). We show that in worst case maximum UG grows linearly with network uncertainy parameter κ in both congested and uncongested networks. We study the gains from the three types of users using computational experiments with different underlying cost distributions.
- ◇ We study toll-pricing when toll-setter faces uncertainty due to the presence of both regret and cost minimizers and toll-setter takes a min-max regret strategy. We formulate it as a zero-sum game and show that a probabilistic pricing will reduce the regret of toll-setter by half.
- ◇ We give single level appoximations of the bilevel toll pricing problem for each type of user.

Using Spectral Information to Precondition Saddle-Point Systems

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We consider the solution by an iterative solver of the (possibly large and sparse) saddle-point linear system

$$\mathcal{A}u = b \equiv \begin{bmatrix} A & B \\ B^T & 0 \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} = \begin{bmatrix} f \\ g \end{bmatrix}, \tag{1}$$

where $A \in \mathbb{R}^{n\times n}$ and $B \in \mathbb{R}^{n\times m}$, with $n \geq m$. We assume that A is symmetric and positive definite and that B has full column rank. Such kind of systems typically arise in constrained nonlinear optimization, as the result for first-order optimality conditions, where $\mathcal{A}$ is known as the Karush-Kuhn-Tucker (KKT) matrix. The assumption of positive-definiteness of A is met, in particular, when solving strictly convex quadratic optimization problems. On the application side, systems structured as (1) where A is naturally symmetric and positive definite arise in CFD or in magnetostatics for instance, from the numerical solution of PDEs or in PDE-constrained optimal control.

We also assume that A and B are possibly ill-conditioned, but that some form of first-level of preconditioning has been applied so that the spectrum of A as well as the singular value distribution of B are both condensed, with relatively few very small eigenvalues and singular values, respectively. Our goal is then to complete this first-level of preconditioning applied separately on A and B in an appropriate manner, so that efficient iterative solutions of the system (1) is ensured despite these trailing sets of extreme eigenvalues/singular values. To this aim, and following our approach, we consider that some good approximation of the spectral information associated to the smallest eigenvalues in A and to the smallest singular values in B is available. In this talk, we will focus on the case where only some good approximation of the spectral information associated to the smallest eigenvalues in A is used (this can be achieved with techniques like those proposed in [1], for instance).

The approach we propose is based on the study by Murphy, Golub and Wathen [2], where the authors show that the "ideal" block diagonal preconditioner

$$\mathcal{P} = \begin{bmatrix} A & 0 \\ 0 & S \end{bmatrix}, \tag{2}$$

in which the exact Schur complement, $S = B^T A^{-1} B$, is incorporated, yields a preconditioned matrix $\mathcal{P}^{-1}\mathcal{A}$ with exactly three distinct eigenvalues (under the assumption of positive-definiteness for A). This property is of practical use when inexpensive approximations of the inverse of A and S are available. We will propose two variants for the block diagonal preconditioning matrix $\mathcal{P}$ in (2) based on a Schur complement approximation derived from the prior spectral information extracted from A directly, i.e., using some good approximation of the subspace associated to the smallest eigenvalues in A. Based on the results provided by Rusten and Winter [3], we study the spectral properties of the preconditioned matrix in both cases and give evidence how one can *recombine appropriately* the available spectral information from the (1,1) block, through the Schur complement approximation, to build an efficient block diagonal preconditioner with little extra cost. We then illustrate through particular linear systems generated during the iteration of an interior-point method, the benefits of this approach when solving systems with the preconditioned MINRES iterative method.

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Coordinate Descent methods for Positive Semidefinite Factorization

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Abstract

Positive semidefinite factorization is a very recent class of matrix factorization problem. A psd factorization of a nonnegative matrix $M \in \mathbb{R}^{m\times n}$ is composed by two sets of symmetric $k \times k$ positive semidefinite matrices: $\{A_1, ..., A_m\}$ and $\{B_1, ..., B_n\}$ such that $M_{i,j} = \langle A_i, B_j\rangle \ \forall\ i,\ j$. The exact factorization is not always possible, so we can see this problem as a nonlinear optimization problem where we try to get the best possible approximation. In this talk, we present the first algorithms to tackle this optimization problem. Results and applications will also be discussed.

Keywords: Positive semidefinite factorization, nonlinear optimization, psd rank, extended formulations

Low-rank factorizations, and more particularly matrix factorizations, are a very important topic in many fields of applied mathematics and computer science. For example, in machine learning, they allow a better understanding of data by reducing dimensions. The conditions imposed on the factors lead to different factorization classes. For example, NMF (nonnegative matrix factorization) is a very popular technique where factors are required to be nonnegative (see [1] and references therein).

Positive semidefinite factorization can be seen as a generalization of NMF. For a nonnegative matrix $M \in \mathbb{R}^{m\times n}$, the problem is to find and assign symmetric $k \times k$ positive semidefinite matrices to each row ($\{A_1, ..., A_m\}$) and to each column ($\{B_1, ..., B_n\}$) of M such that:

$$M_{i,j} = \langle A_i, B_j\rangle, \qquad \text{for } i = 1, ..., m, \quad j = 1, ...n.$$

For $k \geq \min(m, n)$, the problem is trivial. But for $k < \min(m, n)$, the exact factorization is not always possible and this is why the problem can be seen as the following nonlinear optimization problem:

$$\min_{A_i, B_j \in \mathcal{S}^k_+} \sum_{i=1}^{m} \sum_{j=1}^{n} \left(M_{i,j} - \langle A_i, B_j\rangle\right)^2 . \tag{1}$$

The smallest k for which a factorization exists is called the positive semidefinite rank (psd rank) of M and is denoted $rank_{psd}(M)$. This quantity is important in the sense that it is closely related to the field of extended formulations (see [2]).

The talk will be divided in three parts. First, the presentation and the introduction of the subject with the many challenges it represents. Then, in the main part, we present different algorithms based on the Coordinate Descent scheme for solving (1). No algorithm previously existed to solve such problems. And, to finish, we present some results about $rank_{psd}$ obtained with the help of the developed algorithms.

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PHOEG Helps Obtaining Extremal Graphs

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Extremal graph theory aims to determine bounds for graph invariants as well as the graphs that attain those bounds. For example, one can study the number of non-equivalent graph colorings[1] (defined later and called NumCol) and, given a number of nodes and edges, search to minimize it.

Some invariants (including NumCol) may be hard to compute for a human and it might be difficult for one to develop intuitions about how they meld with graph structure.

There is thus a need for tools to help researchers explore the intricacies of these invariants. There already are attempts to reach that goal, e.g., Graph, GrInvIn, Graffiti, AutoGraphiX, Digenes, GraPHedron [2, 3, 4, 5, 6, 7]. However those tools do not meet our needs to obtain extremal graphs in an exact manner and to explore graph transformations. Being able to quickly make queries on graph invariants is also an interesting feature to quickly lighten or kill ideas in a discussion, e.g., "which graphs are local minima for some transformation with respect to some invariant ?" or "on which connected graphs are two invariants equal ?".

Those needs arise from our study of NumCol which is defined as follows. We say that two vertex-colorings of a graph G are *equivalent* if they induce the same partition of the vertex set. The number of non-equivalent proper colorings of a graph G that uses *exactly* k colors is defined as $S(G, k)$ and the *total* number of non-equivalent colorings of a graph G is defined as

$$\mathrm{NumCol}(G) = \sum_{k=1}^{n} S(G, k).$$

Amongst all graphs with n vertices and m edges, we want to find the minimum possible value for NumCol.

In an attempt to answer that question (and others), we are currently developing the Phoeg system, which can be viewed as a successor to GraPHedron. It uses a big database of graphs and works with the convex hull of the graphs as points in the invariants space in order to exactly obtain the extremal graphs and infer optimal bounds on the invariants. This database also allows us to make queries on those graphs as we mentioned it earlier. Phoeg goes one step further by helping in the process of designing a proof guided by successive applications of transformations from any graph to an extremal graph.

This talk will present the difficulties we encounter with the NumCol problem and how the preceding ideas could be used to deal with them.

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On the shelling antimatroids of split graphs

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Many classical problems in combinatorial optimization have the following form.

Problem 1 *For a set system $(V, \mathcal{F})$ and for a function $w : V \to \mathbb{R}$, find a set F of $\mathcal{F}$ maximizing the value of*

$$w(F) = \sum_{f \in F} w(f).$$

For instance, the problem is known to be efficiently solvable for the independent sets of matroids using the greedy algorithm. Since antimatroids capture a combinatorial abstraction of convexity in the same way as matroids capture linear dependence, we investigate the optimization of linear objective functions for antimatroids.

We recall that a set system $(V, \mathcal{F})$, where V is a finite set of elements and $\varnothing \neq \mathcal{F} \subseteq 2^V$, is an *antimatroid* when

$$V \in \mathcal{F}, \tag{AM0}$$

$$\forall F_1, F_2 \in \mathcal{F} \Rightarrow F_1 \cup F_2 \in \mathcal{F}, \tag{AM1}$$

$$\forall F \in \mathcal{F} \text{ and } F \neq \varnothing \Rightarrow \exists\, f \in F \text{ such that } F \setminus \{f\} \in \mathcal{F}. \tag{AM2}$$

The *feasible sets* of the antimatroid $(V, \mathcal{F})$ are the members of $\mathcal{F}$. We call *path* any feasible set that cannot be decomposed into the union of two other (non-empty) feasible sets.

One particular class of antimatroids comes from shelling processes over posets by removing successively the maximum elements. Let $(V, \leq)$ be a poset, then $(V, \mathrm{flt}(V, \leq))$ is a *poset (shelling) antimatroid* when $\mathrm{flt}(V, \leq)$ denotes the family of all filters of the poset.

It is not known whether a general efficient algorithm exists for Problem 1 in the case of antimatroids as shown in the following proposition.

Proposition 1 *The problem of finding a maximum weight feasible set in an antimatroid encoded in the form of its path is not approximable in polynomial time within a factor better than $O(N^{\frac{1}{2}-\varepsilon})$ for any $\varepsilon > 0$, where N is the number of paths, unless $P = NP$.*

Here, we gave a polynomial time algorithm for solving Problem 1 when set system $(V, \mathcal{F})$ is a "split graph shelling antimatroids" which are articular instances of "chordal graph shelling antimatroids". For any chordal graph $G = (V, E)$, we define an antimatroid $(V, \mathcal{F})$ in which $F \subseteq V$ is feasible if and only if there is some ordering $O = (f_1, \ldots, f_{|F|})$ of the elements of F such that for all j between 1 and $|F|$, f_j is simplicial in $G \setminus \{f_1, \ldots, f_{j-1}\}$. The antimatroid resulting from this construction is called a *chordal graph (vertex) shelling antimatroid*. Here we consider the special case of chordal graph shelling antimatroids where the graph is a split graph. These antimatroids will be called *split graph (vertex) shelling antimatroids*.

We have obtained a useful characterization of the feasible sets in a split graph shelling antimatroid.

Proposition 2 *Let $G = (K \cup I, E)$ be a split graph and $(V, \mathcal{F})$ be the split graph vertex shelling antimatroid defined on G. Then a subset F of vertices is feasible for the antimatroid if and only if $N(F)$ induces a clique.*

We use Proposition 2 to establish a connection between the structure of split graph shelling antimatroids and ”poset shelling antimatroids”.

This connection helps us to solve optimization problems on split graph shelling antimatroid.

Proposition 3 *Giving a split graph G (as a list of vertices and a list of edges), the problem of finding a maximum weight feasible set in the split graph shelling antimatroid defined on G can be done in polynomial time.*

We also use Proposition 2 to characterize in simple terms the ”circuits” and ”free sets” of a split graph shelling antimatroid.

Proposition 4 *Let $(V, \mathcal{F})$ be the vertex shelling antimatroid of the split graph $(K \cup I, E)$. Set*

$$\begin{aligned}
C_1 =& \{(\{i,j\},k) : k \in K, i,j \in N(k) \cap I\};\\
C_2 =& \{(\{i,l\},k) : k \in K, i \in N(k) \cap I, l \in (N(k) \cap K) \setminus N(i)\};\\
C_3 =& \{(\{i,j\},k) : k \in K, i \in N(k) \cap I, j \in I \setminus N(k) \textit{ and}\\
& \quad \exists m \in K \textit{ with } i \not\sim m, j \sim m\}.
\end{aligned}$$

Then the collection of rooted circuits of $(V, \mathcal{F})$ equals $C_1 \cup C_2 \cup C_3$. Moreover, the collection of critical rooted circuits equals $C_1 \cup C_2$.

Proposition 5 *Let $G = (K \cup I, E)$ be a split graph with L and J (possibly empty) subsets of respectively K and I. Then $L \cup J$ is free in the vertex shelling antimatroid of G if and only if either there is no edge between L and J, or there exists some vertex h in J such that $L \subseteq N(h)$ and $N(J \setminus \{h\}) \subseteq N(h) \setminus L$.*

Assessing risk in geographic contexts: formal models

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Locating a facility or implementing a project at some place or another can result in milder or more severe impacts from a risk management point of view. How can we compare different facilities or projects implementations taking into account the local vulnerability and the implied hazard in an integrated manner? This work presents some models that enable to rank maps representing the spatial distribution of the risk implied by different projects. These models are characterized by formal properties. We illustrate this approach on the evaluation of variants of an industrial project.

A dynamic model of a non-life insurance company

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An analysis of optimal investments in technical capacity, goodwill, and financial portfolios to maximize the long term profit of a non-life company is conducted using Optimal Control Theory. Technical capacity affects both the claim ratio and the number of policies while goodwill affects only the number of policies. Financial portfolio is assumed to be optimally managed hence it is not analyzed.

Mathematically technical capacity (T) is assumed to obey the following differential equation:

$$T' = \frac{dT}{dt} = q - \delta T$$

Therefore, technical capacity increases by the investments (q) made in underwriting personnel, their education, software and hardware for technical analysis, and decreases by the obsolescence of technical methods and the depreciation of hardware at a rate δ. Goodwill (G) is assumed by to obey the following differential equation:

$$G' = a - \eta G$$

where (a) denotes the investment made in quality and advertising,and η denotes the exponential rate of decline of goodwill.

In a competitive insurance market (where price is constant), the profit of a company at any time t is expressed as:

$$\Pi = p.N(G,T) - p.N(G,T).H(T) - q - w(a)$$

N represents number of policies sold; $H(T)$ represents the claim ratio; q and a represent the investments made in technical capacity and goodwill respectively; $w(a)$ represents the convex cost function of goodwill expenditures. The objective of the company is to maximize discounted profits over the infinite horizon.

Analysis of the differential equations representing the necessary conditions for the solution of the problem gives the following results:

1. The company with lower than required goodwill at the beginning should increase the expenditures in both goodwill and the technical capacity at an increasing rate if the impact of technical capacity on claim ratio is greater than its impact on the number of customers.

2. The company should first invest heavily in goodwill to increase the number of customers and then increase the investment in technical capacity to decrease the claim ratio if impact of technical capacity on claim ratio is less than its impact on the number of customers.

3. A sudden drop in the level of goodwill can be increased by investment quality and advertising. Reinsurance is not included in the model since this function is a partnership (with re-insurers) function. Other expenses are assumed to be constant and hence they do affect the solution.

Controlling Excess Travel and Assignment Switches in School Location

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Rapid growth in urban peripheries combined with the desire of individuals wishing to live back into the city poses serious long-term planning challenges for public facilities. In those situations, modifying an existing network of public facilities is necessary to meet anticipated changes in the level of demand. We present a bi-weighted location model that minimizes excess travel and reduces changes in school assignments over a limited time horizon. The flexibility of our model also resides in its ability to (1) limit the number of schools that recently opened to close, and (2) to modify school capacities to accommodate demand fluctuations over the time horizon considered. We test the robustness of our model under for different space-time granularities and weighting schemes. We present an application to the Charlotte-Mecklenburg School located in the fastest growing county of North Carolina, U.S.A. Solutions of the proposed model are highly sensitive to the geographic distribution of the demand: the addition of new schools is critical in peripheries where demand may grow rapidly, while modular equipment is necessary when demand exceeds permanent school capacity, especially in the inner sections of the city where schools cannot be closed due to age restrictions. We also identify regions of assignment instabilities. The proposed model is beneficial to policy-makers seeking to improve the provision and efficiency of public services.

Keywords: Dynamic school location, assignment switch, non-closest assignment, capacity constraints, GIS.

A Test for Single-Peaked Preferences

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Preferences play an important role in many areas of research. When faced with different alternatives, be it different cars, candidates in an election, budgets, etc., it is commonly assumed that people have a preference ordering over all of these alternatives, ranking them from best to worst. Often the nature of the alternatives restricts the possible preferences in some sense. An important such restriction is given by *single-peakedness*, introduced by Black [3]. Suppose a linear ordering exists, which ranks all alternatives along a line. An agent's preferences are then single-peaked if he has a most preferred alternative, the *peak*, and when comparing two alternatives that are both on the same side of the peak, the alternative closest to the peak is preferred. This restriction has gained central importance in the areas of political science and social choice.

Given the importance of single-peaked preferences, it is of interest to test if and in which situations agents hold such preferences. On the subject, a number of papers have appeared (Bartholdi and Trick [2], Escoffier et al. [4] and Ballester and Haeringer [1]). One common factor in these papers is that they test for single-peakedness given the full preference orderings of all agents. However, there are several drawbacks to using this kind of data. First, it assumes that choices are made based on preference orderings as opposed to some heuristic decision rule. Second, even if this assumption is correct, there is a high risk that the ordering is misreported. This can be due to simple error, as ranking all alternatives is a complex task, or because the agent has little incentive to determine his ranking over average alternatives.

In this paper, it is also our goal to provide a way of testing for single-peakedness. Specifically, we will use the dominant setting for experiments in choice behaviour research, two-alternative forced choice. In this setting agents are faced with choices between two alternatives, and must choose one. A large number of such choices are given, including repetitions of the same choice situations. In the simplest situation, agents will consistently make the same choice when faced with repetitions of choice situations. However, it is very common that agents exhibit choice reversals. The data resulting from such experiments is thus, for every pair of alternatives, a rate with which one alternative is chosen over another.

To test for single-peaked preferences, while being able to account for choice reversals, we will make use of a so-called mixture model [5]. This model states that at any given point in time, the agent has a single-peaked preference, but that these may be different single-peaked preferences at different points in time. The data is consistent with this model if there exist single-peaked preferences, and a probability distribution over these preferences, such that the probability that the agent holds a preference in which she prefers one alternative over another is equal to the rate at which she chooses that alternative over the other. The conditions such mixture models impose on data have been studied for a number of different classes of decision rules. An important contribution from Suck [6] shows the equivalence of testing mixture models and the membership problem of a polytope associated with the class of preference orderings studied. For example, testing a mixture model of general linear preference orders is equivalent to the membership problem for the linear ordering polytope.

The main contributions of this paper are as follows.

- ◇ Given an ordering of the alternatives and the rates of choice, we provide necessary and sufficient conditions for testing a mixture model of single-peaked preferences. These conditions can be tested in $O(n^2)$ time.
- ◇ We provide a polynomial time algorithm which given the rates of choice, provides an ordering of the alternatives for which a mixture model of single-peaked preferences is satisfied (if such an ordering exists). This algorithm also runs in $O(n^2)$.

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Improving Order Picking Efficiency by Analyzing the Combination of Storage, Batching, Zoning, and Routing Policies in a 2-Block Warehouse

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As customer markets globalize, supply chains are increasingly depending on efficient and effective logistic systems in order to distribute products in a large geographical area. Warehouses are an important part of supply chains, and therefore warehouse operations need to work in an efficient and effective way. Warehouse operations can be classified into four categories, including receiving, storage, order picking, and shipping [2].

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. The changed order behavior can be ascribed to upcoming e-commerce markets and forces warehouses to handle a larger number of orders, while order picking time has shortened. Therefore, order picking management, in particular efficiently and effectively organizing order picking operations, has been identified as an important and complex activity [1].

One way to obtain a more efficient order picking process is to allocate fast moving products to storage locations closely located to the depot, rather than randomly assigning stock keeping units (SKUs) to storage locations. Storage location assignment policies define rules to assign SKUs to individual storage locations in order to minimize the order picker travel distance. As traveling in a warehouse is often the dominant factor in order picker's activities, a travel distance reduction will contribute to a more efficient order picking process [5].

Furthermore, batch picking, instead of picking each order separately, allows warehouses to handle a larger number of orders in shorter time windows. By picking multiple orders in a single picking tour, the order picker travel distance per order will be reduced. The order batching problem is concerned with deciding on the rules defining which orders to combine in a picking tour in order to minimize the order picker travel distance [1] [3].

Another practice of moving to a more efficient order picking process is dividing a warehouse into different smaller areas, being order picking zones. Each order picker is assigned to a single zone and is responsible for picking all SKUs of an order belonging to this zone. As a consequence each order picker travels in a pre-specified part of the warehouse and thus travel distance will be reduced [1].

Finally, shorter order picking routes contribute to a more efficient order picking process. Given a pick list with a number of storage locations to visit, routing policies determine the sequence in which the SKUs on the pick list are to be retrieved, with the aim of composing short order picking routes [4].

While the number of publications dealing with one specific warehouse operation area is extensive, only a limited number of researchers examine different warehouse processes simultaneously, even though the efficiency of different warehouse policies is interdependent [2]. Especially the effect of zoning in combination with other order picking decisions, such as storage, routing and batching, has received little research attention. This research focuses on several decisions related to order picking activities. A real-life case study demonstrates the value of studying the combined effect of storage, order batching, zoning, and routing policies in order to minimize the distance traveled by order pickers.

The objective of this research is to evaluate several storage, batching, zoning, and routing policies simultaneously in order to reduce the order picker travel distance, resulting in a more efficient order picking process. In the simulation experiment of this paper five different storage location assignment policies, two different batching algorithms, strict order picking and zone picking, and five different routing heuristics are analyzed. The zone picking experiment is further analyzed by changing the number of order picking zones as well as the storage zone assignment policy.

The main contribution of this research is a real-life case study on how order picking activities may be improved by analyzing different storage, order batching, zoning, and routing policies simultaneously. Furthermore, a multilevel regression provides insight into the impact of each individual order picking policy on the distance traveled by order pickers, as well as interactions between storage, batching, zoning and routing policies.

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Truck dispatching in a tank terminal

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Large-scale manufacturing of products, such as gases and chemicals, requires adequate storage facilities. While tank terminals may store these products, the necessary transportation to and from terminals is not included. Consequently, clients outsource transport requirements to external contractors. Employing these contractors may incur additional costs when delays within the tank terminal itself exceed a certain threshold.

While the type of vehicle employed to transport products varies, this paper's focus exclusively concerns trucks. Trucks load or unload their cargo at the loading yard. The layout of the loading yard implicitly introduces a blocking constraint: a stationary truck preventing another truck from reaching its destination further on in the loading yard. Although scheduling problems in container terminals have been extensively discussed [1], scheduling in tank terminals has not yet been academically addressed. Currently, it is the responsibility of truck schedulers to assign each truck to its loading position. Schedulers dispatch trucks on a first-come-first-served basis whereby the first truck whose loading position is available and reachable is sent through the yard. Presently, there is no evidence whether the applied dispatching rule is efficient or not. Thus, the primary objective of this research is to reduce the average blocking time via optimization and decision support, resulting in a more efficient schedule.

The focus of this work is on the algorithm employed to minimize the total blocking time and various other important objectives. The proposed algorithm finds a dispatch order for the trucks followed by the construction of a feasible schedule via a schedule generator. The schedule generator takes the dispatch order and the loading position to which each truck is assigned and constructs a schedule from this input while simultaneously respecting all necessary constraints (including the blocking constraint). When offering terminal customers a competitive service it is important to address not only the average blocking time, but also to minimize the additional costs experienced when contractual handling times are exceeded. Certain possible approaches capable of achieving this are to consider either the total number of trucks violating this soft constraint or the total amount of time each truck has violated their contractual handling time.

Instances, which include truck arrival times and the specific product processed, are made available by the tank terminal of Oiltanking Stolthaven Antwerp NV (OTSA) for the experiments conducted. These instances provide a means of comparing our algorithm's schedules against the manually-generated schedules created by truck schedulers.

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Flexible Hub Assignment of Flows for the Air Express Shipment Service Network Design

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The Service Network Design problem arises for carriers that need to determine which routes to operate at the minimal possible cost, offering a high quality service in terms of speed, flexibility and reliability. The express integrators are one of the carriers that face such a problem. They offer overnight, door-to-door delivery of shipments, within regions as large as the US, Europe or the Middle East. Changes in the design of their operative network are expensive and limited to the availability of resources, e.g., airport slots, number of aircrafts, handling capacity of the facilities. As a result, they design networks that repeat the same schedules every day during months.

For connecting all the origins with all the destinations, they have three processes. The *pickup process* consolidates the shipments, in stages, by transporting them from the origin customers to ground stations, then to airport facilities called gateways, and then to hubs. The hubs are large airport facilities that perform the *sorting process*, i.e. they receive the shipments ordered by origin and sort them by destination. The *delivery process* deconsolidates the shipments by transporting them from hubs to gateways, to stations, and to the final customer. Typically for both the pickup and delivery processes, the movements are performed with vans between customers and stations, with trucks between stations and gateways, and with aircrafts between gateways and hubs.

From all the operative costs, the most important by far are those related with the aircrafts. Thus, it is a critical task for the express companies to design an efficient network of flights that enables the overnight flow of shipments from their origin gateways to their destination gateways. Such task is known as the Air Express Shipment Service Network Design (AESSND). It forms a sub-class of the service network design problem since the express carriers must also consider specific behaviors for the routes and hubs.

The routes have four main characteristics. First, they have to respect the windows of times for loading and unloading the shipments at hubs and gateways. Second, they have to observe the curfew and slot constraints imposed by the airports. Third, for each aircraft type, the number of equipments used in the network cannot surpass the number available. Finally, for ensuring the operations repeatability each day, routes must be selected such that each gateway and each hub start and end with the same number of aircrafts, of the same types. For the hubs there are two elements to consider. First, their sorting capacity per unit of time has to be respected. Second, if there is more than one hub within a region, the allocation of shipments to hubs becomes a critical decision, known as the *hub assignment*. When the hub assignment is provided as an input to the AESSND, it is referred as a *fixed hub assignment*. If the hub assignment is an explicit decision of the AESSND, then it is called a *flexible hub assignment*.

In this research, we develop an optimization model for addressing the Air Express Shipment Service Network Design problem, for the next day deliveries within a region, with two hubs and flexible hub assignment. We provide a reformulation of this multi-commodity network design problem that improves the LP relaxation and reduces the number of variables and constraints. We also strengthen the LP relaxation with three families of valid inequalities: strong linking inequalities, strong cutset inequalities, and commodity connectivity constraints. Then, our model is tested using extensive numerical experiments to show the value added in terms of efficiency and effectiveness. First, a comparison of our approach to the different formulations in the literature is presented on reduced size instances (20 gateways). Then, the performance of our model is presented for variations of these same instances, were the demand, the sorting capacity, the number of equipments, the distance between hubs, and the number of gateways are varied. Finally, the performance of our model is analyzed on realistic instances in the European region.

A best fit decreasing algorithm for the three dimensional bin packing problem with transportation constraints

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In this work, we consider the problem of selecting containers in order to pack a set of cuboid boxes while minimizing the unused space inside the selected containers. The set of boxes is highly heterogeneous while there are few types of containers to select. In the literature, this problem is called a three dimensional Multiple Bin Size Bin Packing Problem (MBSBPP).

As it is the case for the packing problems, the pattern has to satisfy geometry constraints: the items cannot overlap and have to lie entirely inside the bins. The richness of our application is to deal with additional and common constraints: the bin weight capacity, the rotations of the boxes, the stability and the fragility of the boxes and the last but not the least, the uniformity of the weight distribution inside the bins. In addition to this, in the context of air transportation, bins are called Unit Load Devices (ULD). A ULD is an assembly of components consisting of a container or of a pallet covered with a net, so as to provide standardised size units for individual pieces of baggage or cargo, and to allow for rapid loading and unloading. ULDs may have specific shapes to fit inside aircraft.

This specific problem has been formulated as a MIP and then studied through MIP-based constructive heuristics. The aim of the present work is to find good initial solutions in short computational times. We develop here a best fit decreasing algorithm (BFD) designed for this specific problem as it showed interesting results in terms of worst-case performance ratio for the one dimensional bin-packing problem. As a reminder, the BFD first sorts the list of items by non increasing size and then considers one item after another. Then, it assigns an item to the feasible bin (if any) having the smallest residual capacity. If there is no such bin, then a new one is created. However, the adaptation of this algorithm is far from trivial: several rules for sorting the items and the bins exist and placing a box in a bin can also be achieved in different ways. In particular, the choice of placement points is a major challenge in multi-dimensional packing or cutting problems. Indeed, the space utilization and the solution quality are highly influenced by the item-positioning rule. This issue is particularly crucial and difficult to manage for three dimensional situations.

We based our algorithm on the concept of *Extreme Point* (EP) from Crainic T.G., Perboli G. and Tadei R. (2008). The EPs represent the interesting possible positions to accommodate items. We modify this concept as well as the choices of sorting rules to take into account the different constraints of our problem. The algorithm is tested on real data sets and the results are compared to those obtained with a traditional branch-and-bound resolution.

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Train load planning optimization: state-of-the-art and opportunities for future research

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Efficient freight handling systems can help to make intermodal transportation more attractive and consequently help to expand its market share [1]. At the operational decision level of a rail-road terminal, this can be achieved by optimizing the load planning of intermodal trains. The train load planning problem deals with the assignment of load units to a location on an intermodal train [4]. It can have a significant influence on the time and energy spent on handling load units. Bruns and Knust [3] indicate that usually demand for rail transportation is larger than the capacity of trains. Therefore, it is important to determine which load units will be loaded, and on which location on the train, to maximize the train's loading degree and minimize costs per load unit.

Companies perform the assignment of load units to a specific location on a train largely manually. Automation of this task can optimize train load planning, but little research has been conducted on this topic [4]. Train loading models can assist train planners in their decision making process and help to optimize train load planning, which results in large cost savings. In this paper, we review existing literature and identify opportunities to optimize and automate train load planning problems.

Several factors influence the loading plan. A number of performance indicators can be proposed, depending on the type of decision maker involved, namely the terminal or the network operator. An important measure for the network operator is the loading degree. On the contrary, the terminal operator aims at minimizing costs of handling operations at the terminal during execution of the load plan. Furthermore, characteristics of the train components, as well as a number of context-specific operational constraints restrict the loading possibilities. The weight and length a train can carry are limited. How many and which types of load units can be loaded on a wagon, as well as the maximum weights per slot and wagon, are specified in the loading patterns [3].

Finally, the dynamics of the planning environment influence the problem context. Current scientific literature mainly focuses on static problems. However, whenever uncertain events trigger changes to the plan, this needs to be reflected in the load plan immediately in order for train planners to communicate this to other parties involved. Static formulations can be used in a specific train planning environment, when terminals receive all load units before loading the train and all information is known with certainty. However, operational train planning decisions require dynamic planning related to the uncertainty of daily real-time operations.

Future research will focus on the formulation of realistic load planning problems. Furthermore, only recently uncertainties about input data are examined [2]. In a real-world planning environment, train planners look a number of days ahead to establish a first load plan. One day before train departure, loading plans are established and the network operator sends them to the terminal operator. The initial loading plan should be updated to include revisions to the loading plan when unexpected events or changes to the input data occur.

Furthermore, when assigning load units to trains, it may be interesting to provide train planners with a longer term view on current capacity plans and address possible issues when they occur. Moreover, current literature assumes that the departure terminal is known and fixed when operators establish load planning problems. When two or more intermodal terminals are located near each other in the same service area and both have train departures to the same destination terminal, it might be interesting to consider departing trains from both terminals to optimize capacity utilization of both departing trains jointly. Finally, current models mostly combine the maximization of the train utilization with the minimization of handling costs at the terminal. However, both objectives are often considered separately in real-life. It may be interesting to consider the effect of a load plan composed by optimizing train utilization on the terminal operations and evaluate the benefits of integrated decision-making.

The train load planning problem is becoming highly complex when all relevant constraints and dynamic influences are considered. Moreover, in a dynamic planning environment in which decisions are made in real-time, the computation time to establish a feasible loading plan is important. Therefore, it would be interesting to further explore the possibility to develop efficient heuristics for this problem.

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A Decision Support System for Synchromodal transport

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The growing cargo demand, increasing road congestion as well as reliability, safety and environmental concerns are pushing researchers, transport operators and policy makers to develop and deploy more efficient freight transport solutions. Given these developments, the current transport setting needs a modal shift towards modes with a smaller societal impact. Critical issues in this perspective are the modal choice preferences and transport mode selection [1, 2, 3, 5, 7, 8]. The findings of the modal choice literature often yield higher user preferences related to road transport based on the user's needs. Intermodal transport, which is a combination of two or more modes in a single journey [12], provides more options and opportunities for a positive modal shift. However, the development of intermodal decision support models, where more actors and modes are incorporated (compared to unimodal), are hampered by limited data availability and its static nature [6]. The latest synchromodality concept presents an extension of intermodal transport by including real-time re-routing of loading units over the network to cope with disturbances and operational or customer requirements [13, 14]. Thus, appropriate solution approaches are necessary to facilitate decision support and transport optimization in real-time. Unexpected data changes caused by disturbances or other events result in congestion, delays and time/money losses. The incorporation of real-time and dynamic elements can facilitate re-routing, re-scheduling and modal shift, contributing to higher competitiveness [9]. With regard to these dynamic characteristics of transport, [11] focus on a routing problem in a multimodal network. Furthermore, [15] propose a multimodal routing problem solution with time windows in order to find a transport route with the best transport combination. Due to the widespread use of modern communication technologies, some promising real-time freight control models have been introduced. For instance, [4] devised an innovative real-time-oriented freight control approach, integrating multiple transshipments in a transport system subject to disturbances. However, most of the studies take a single forwarder perspective without a holistic combination of the wide variety of transport actors and different modes in real-time management. Thus, the proposed PhD project will take advantage of the available literature advances related to multimodal routing and real-time modeling with disturbance elements in order to provide such a holistic combination. The synchromodal concept may offer better performance than intermodal transport on flexibility, reliability and other modal choice criteria. The synchromodal notion has received limited attention in terms of modeling and cost-effectiveness [10, 13] and no attention in terms of disturbances and blockages.

The aim of the project is to develop and delineate a synchromodal theoretical framework which will be empirically utilized in terms of an innovative dynamic assignment model. This model will assist in the dynamic allocation of freight flows within a synchromodal context by using a re-optimization algorithm. The model will assign the freight movements to the multimodal network according to user preferences (transport time, price, reliability and environmental performance) and transport system capacity. The transport system capacity will make use of an innovative approach that integrates infrastructure capacity (road, rail slots, inland waterways) with service capacity (vehicle capacity, frequency). The outcome will express the most appropriate transport service and quality characteristics that are needed to transport a given payload. The new synchromodal framework will be further integrated in an existing decision support system and consequently validated. The final evaluation of the project will be based on the stakeholder criteria and preferences by using the Multi Actor Multi Criteria Analysis. This will lead to identification of policy measures to further stimulate the synchromodal concept and delineate its role for broader implementation.

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Equilibriums in multistage transport problems

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Search of equilibrium or stochastic equilibrium in multistage models of transport flows results in the solving of saddle-point problem with the convex-concave structure :

$$\min_{\substack{\sum_{j=1}^n x_{ij} = L_i, \\ \sum_{i=1}^n x_{ij} = W_j, \\ x_{ij} \geq 0 \\ i,j=1,\dots,n}} \max_{y\in Q} \left\{ \sum_{i,j=1}^n x_{ij} \ln x_{ij} + \sum_{i,j=1}^n c_{ij}(y) x_{ij} + g(y) \right\}, \tag{1}$$

where $c_{ij}(y)$ and $g(y)$ are concave functions which can be non-smooth,

$$L, W \in \Sigma_n(1) = \left\{ z \in \mathbb{R}^n_+ : \sum_{i=1}^n z_i = 1 \right\},$$

Q is simple closed convex set. The dual problem for (1) is written in the form (2).

$$\max_{y\in Q} \max_{\lambda,\mu\in\mathbb{R}^n} \left\{ \langle \lambda, L \rangle + \langle \mu, W \rangle - \sum_{i,j=1}^n e^{-c_{ij}(y)-1+\lambda_i+\mu_j} + g(y) \right\} = -\min_{y\in Q}(f(y) - g(y)) \tag{2}$$

We propose a two-level algorithm to solve this problem. On the lower level we use Sinkhorn algorithm [1] to find the approximate value and approximate subgradient of the function $f(y)$. It is known that Sinkhorn algorithm has linear rate of convergence. We use this fact to prove that the approximation of function $f(y)$ value and subgradient can be found with any given accuracy δ for the price of $O\left(\ln \frac{1}{\delta}\right)$ arithmetic operations. Here the approximation is meant in the sense of (δ, L)-oracle.

D e f i n i t i o n 1. (δ, L)-oracle provides $(F(y), G(y))$ and that $(F(y), G(y))$ for any $y, y' \in Q$satisfy

$$0 \leq f(y') - F(y) - \langle G(y), y' - y \rangle \leq \frac{L}{2} \|y' - y\|^2 + \delta. \tag{3}$$

Since we don't know the level of smoothness of the function $f(y) - g(y)$ and since only the (δ, L)-oracle is available for this function, we extend Universal Gradient Methods from [2] for the case of inexact oracle and use these new methods as upper level methods. We prove the convergence result for the constructed two-level method for solution the problem (1).

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Modelling traffic dependent lock capacity with combinatorial Benders' decomposition

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Waterborne multimodal transportation is becoming an increasingly important part of the logistics chain given its comparatively low pollution levels when compared to other transportation methods. Analysis of the increased traffic flows on rivers and canals indicates, however, that locks will soon become a major bottleneck for inland waterway transportation. Inland waterway operators are thus facing the significant challenge of scheduling their waterway's series of locks in such a way that the transit time of ships traversing the waterway is minimized. The serial Lock Scheduling Problem (sLSP) is the combinatorial optimization problem corresponding to this increasingly difficult challenge for inland waterway operators.

A combinatorial Benders' decomposition for the single-chamber serial lock scheduling problem is presented. This approach enables a straightforward transition from fixed/infinite capacity models to those with traffic-dependent lock capacity at little to no additional computational cost. The presented decomposition approach considers the original fixed/infinite capacity model as the Master Problem and evaluates the traffic dependent capacity constraints in a sub problem. By adding combinatorial Benders' cuts to the Master Problem before and during the solution process, it quickly converges to a feasible and optimal traffic dependent capacity sLSP solution.

The method's performance is evaluated on a large set of small to medium sized instances, analysing the influence of traffic dependent lock capacities on both the ship waiting time and total computation time. The results demonstrate how the total required computation time of both models are within the same interval, thus highlighting the efficiency of the presented decomposition approach. For larger lock capacities, the decomposition approach is consistently faster than its fixed capacity counterpart. Furthermore, the results reveal significant differences in ship waiting times between fixed/infinite and traffic dependent models on the instances with real-life ship sizes. These results indicate that traffic dependent lock capacity is a prerequisite for an accurate prediction of ship waiting times in realistic scenarios where ships of different sizes are handled by the lock.

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