Gesellschaft für Operations Research e.V.

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GOR-Arbeitsgruppe: Praxis der Mathematischen Optimierung

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Herewith we would like to invite you to the 89th meeting of the GOR working groups "Real World Mathematical Optimization" in the Physikzentrum Bad Honnef (Hauptstr. 5, 53604 Bad Honnef, http://www.pbh.de). This meeting is hold as a symposium with the topic

Hybrid Methods

The workshop starts on **15.11.2011** at **09:30** and ends on **16.11.2011** at about **16:00**.

The working language will be preferably English, since some speakers or participants are expected from abroad.

Please note that the participation in a GOR-AG-Workshop for non-members is subject to a registration fee, unless you are a speaker or a host.

Please send your confirmation of participation (via e-Mail or Fax is possible) as soon as possible but not later than 17.10.2012. The latest information on the meeting is available on the homepage of the GOR working Group (https://gor.upb.de/index.php?id=54).

Yours sincerely,

Josef Kallrath & Steffen Rebennack
(GOR AG) (Colorado School of Mines)

Hybrid Methods

This symposium is about real world problems which are solved using methods from exact mathematical optimization and heuristics. Hybrid techniques combine exact optimization algorithms and constructive heuristics, or improvement methods (local search, or metaheuristics such as simulated annealing, genetic algorithms, tabu search and so on). They are a subset of polylithic modeling and solution techniques in which the output of one model is the input of another optimization model.

In constructive heuristics we exploit the structure of the problem and compute a feasible point. Once we have a feasible point we can derive safe bounds on the optimum and assign initial values to the critical discrete variable which could be exploited by MILP solvers. Feasible points can be generated by the structured primal heuristics, e.g., *fix-and-relax* or sequences of relaxed models, or by *unstructured heuristics* tailor-adjusted to the problem structure and difficult to transfer to other problems. Developing unstructured, problem-specific heuristics is the art of computing with good feasible point in short times -- everything is allowed.

What is the benefit of all these efforts? The set of solvable real-world problems is extended both in quality (structure) and size (number of variables and constraints). There is on the one hand, indeed more effort to setup and maintain solution based on hybrid methods, but on the other hand, algebraic modeling systems become more and more suitable to support such approaches. The more these techniques will be used, the more will the edge of solvable real-world problems be moved to larger and more complex problems.

This two-days event will attempt to give an overview of the current state of the art of hybrid methods, sometimes also called *matheuristics*. Please contact Steffen Rebennack or myself if you are interested to contribute a talk or a presentation.

In talks, each approx. 40 to 50 minutes experts from practice, research institutions or software companies, will present selected problems and the corresponding solutions. Confirmations for their talks have been obtained from the following speakers:

Dr. Michael Bussieck & Dr. Lutz Westermann (GAMS GmbH, Braunschweig, Germany)
Rapid Prototyping of Decomposition Algorithms

Prof. Dr. Sebastian Engell (TU Dortmund, Dortmund, Germany)
Risk Conscious Planning under Uncertainty by a Multi-Objective Hybrid MILP/Evolutionary Algorithm

Frederik Fiand (TU Braunschweig, Braunschweig, Germany)
A Student Administration and Scheduling System for Federal Law Enforcement Training Centers

Dr. Hermann Gold (Infineon Technologies AG, Regensburg, Germany)
Concurrent Dynamic Optimization of Routing and Sequencing in a Semiconductor Wafer Fab

Dr. Susanne Heipcke (FICO, Xpress Team, Birmingham, UK)
Implementing Decomposition Approaches for Concurrent and Distributed Solving

Prof. Dr. Josef Kallrath (Weisenheim am Berg, Germany)
Polylithic Modeling and Solution Approaches

Prof. Dr. Steffen Rebennack (Colorado School of Mines, Golden, Coloroda, USA)
Combining Sampling-based and Scenario-based Nested Benders' Decomposition Methods

Dr. Sleman Saliba (ABB Corporate Research, Ladenburg, Germany)
A Hybrid Algorithm for Production Optimization and Scheduling on a Hot Rolling Mill

Dr. Maren Urselmann (TU Dortmund, Dortmund, Germany)
Optimization-based Chemical Process Design by Memetic Algorithms

Prof. Dr. Stefan Voss (University of Hamburg, Hamburg, Germany)
Matheuristic Approaches for Solving Reliability Problems

In particular, the following thematic fields will be addressed:

- Cutting Stock Problems
- Energy Industry
- Process Design
- Scheduling Problems
- ……

We expect an interesting overview on the field and exciting discussions. Part of the official program is a visit and a guided tour through the private house of the first German chancellor, Konrad Adenauer.

GOR Gesellschaft für Operations Research e.V.

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89. Sitzung der GOR Arbeitsgruppe
Praxis der Mathematischen Optimierung

Hybrid Methods

Physikzentrum, Bad Honnef, November 15 & 16, 2012

Thursday, Nov. 15 - 2012 : 09:30 – 22:00

09:30-09:40 **Opening and Welcome Session** (J. Kallrath & S. Rebennack)

09:40-10:30 **Josef Kallrath** GOR Arbeitsgruppe, Weisenheim am Berg, Germany
Polylithic Modeling and Solution Approaches

10:30-11:00 ------------------------------ Coffee Break ---------------------------------

11:00-12:00 **Prof. Dr. Sebastian Engell** (TU Dortmund, Dortmund, Germany)
Risk Conscious Planning under Uncertainty by a Multi-Objective Hybrid MILP/Evolutionary Algorithm

12:00-13:00 -------------------------- Lunch Break ---------------------------------

13:00-13:45 **Dr. Maren Urselmann** (TU Dortmund, Dortmund, Germany)
Optimization-based Chemical Process Design by Memetic Algorithms

13:45-14:30 **Dr. Sleman Saliba** (ABB Corporate Research, Ladenburg, Germany)
A Hybrid Algorithm for Production Optimization and Scheduling on a Hot Rolling Mill

14:30-14:50 ------------------------------ Coffee Break ---------------------------------
14:50-16:30 ----- Visit & Guided Tour: Stiftung Bundeskanzler-Adenauer-Haus --------

17:00-18:00 **Dr. Susanne Heipcke** (FICO, Xpress Team, Birmingham, UK)
Implementing Decomposition Approaches for Concurrent and Distributed Solving

18:00-18:15 **Internal Meeting** of the Working Group

18:30 - **Conference Dinner** – Buffet; get-together in the wine-cellar
Celebrating the 85th Meeting of our GOR Working Group

Friday, Nov. 16 - 2012 : 09:15 – 16:30

09:15-10:15 **Prof. Dr. Stefan Voss** (University of Hamburg, Hamburg, Germany)
Matheuristic Approaches for Solving Reliability Problems

10:15-10:45 -------------------------- Coffee Break ---------------------------------

10:45-11:45 **Dr. Michael Bussieck & Dr. Lutz Westermann & Alexander Meeraus**
(GAMS GmbH, Braunschweig, Germany)
Rapid Prototyping of Decomposition Algorithms

11:45-12:45 **Prof. Dr. Steffen Rebennack** (Colorado School of Mines, Golden, USA)
Combining Sampling-based and Scenario-based Nested Benders' Decomposition Methods

12:45-14:00 ------------------------------------- Lunch Break ----------------------

14:00-14:50 **Dr. Hermann Gold** (Infineon Technologies AG, Regensburg, Germany)
Concurrent Dynamic Optimization of Routing and Sequencing in a Semiconductor Wafer Fab

14:50-15:20 **Frederik Fiand** (TU Braunschweig, Braunschweig, Germany)
A Student Administration and Scheduling System for Federal Law Enforcement Training Centers

15:20-16:00 **Final Discussion – End of the Workshop – Coffee Break**

The Speakers

Michael R. Bussieck is a Senior Research Analyst at GAMS Software GmbH. From 1999 to 2004 he worked at the GAMS Development headquarters in Washington DC, USA. He received his Ph.D. from Technical University Braunschweig, Germany.

Sebastian Engell received the Dipl.-Ing. degree in electrical engineering from Ruhr-Universität Bochum, Bochum, Germany, in 1978, and the Dr.-Ing. degree and the Venia Legendi in automatic control from Universität Duisburg, Duisburg, Germany, in 1981 and 1987, respectively. From 1984 to 1985, he was a Post-Doctoral Researcher with McGill University, Montréal, QC, Canada. From 1986 to 1990, he was the Head of a Research and Development Group, Fraunhofer Institut IITB, Karlsruhe, Germany. In 1990, he was appointed to his present position as a Full Professor of process dynamics and operations with the Department of Biochemical and Chemical Engineering, University of Dortmund, Dortmund, Germany. He was the Department Chairman from 1996 to 1999 and Vice-Rector for Research from 2002 to 2006. His current research interests include control and scheduling of chemical processing systems, hybrid systems, and optimization-based process design.

Frederik Fiand studies Financial Mathematics and Mathematical Economics at Technical University Braunschweig, Germany. His major subject is Mathematical Optimization and for his diploma thesis he is supported by the GAMS Software GmbH.

Hermann Gold is a Senior Staff Engineer at Infineon Technologies AG, where he is working on planning and scheduling problems in semiconductor manufacturing. He studied computer science at the University of Erlangen and received a doctorate degree from the Faculty af Mathematics at the University of Würzburg. His special research interest is in the combination of queueing theory and optimization.

Josef Kallrath obtained his PhD in astrophysics from Bonn University (Germany) in 1989. He is a professor at the University of (Gainesville, FL, www.astro.ufl.edu/∼kallrath), and solves real-world problems in industry using a broad spectrum of methods in scientific computing, from modeling physical systems to supporting decisions processes by mathematical optimization. He has written review articles on the subject, about 70 research papers in astronomy and applied mathematics, and several books on mixed integer optimization, as well as one on eclipsing binary stars.

He leads the Real World Optimization Working Group of the German Operations Research Society. His current research interests are polylithic modeling and solution approaches to solve large-scale or difficult optimization problems, for instance, by decomposition techniques such as column generation, or hybrid methods.

Susanne Heipcke worked for BASF-AG, Germany, before joining Dash Optimization in 1998. Her Ph.D. research (awarded in 1999 by the University of Buckingham) focused on the solution of large-scale industrial problems by a combination of constraint programming and mixed integer programming. More recently she has worked on various aspects of modeling, including the development of teaching material for Mosel (including the book "Applications of optimization with Xpress-MP" published in September 2002), and interfaces to different types of solvers and solution methods. In 2001-2004 she has participated in teaching the course on mathematical modeling in the OR master program at the University Aix-Marseille II. Her responsibilities at FICO comprise the model builder library Xpress-BCL, contribution to the development and design of Mosel, consulting projects in various business sectors, training courses and the organization of specialist training events.

Steffen Rebennack is an Assistant Professor at the Colorado School of Mines, USA. He obtained his PhD at the University of Florida. His research interests are in dimension-reduction techniques for large-scale optimization problems, particularly with applications in power systems, stochastic optimization and global optimization.

Sleman Saliba is scientist at ABB Corporate Research Germany, where he is deputy Group Leader of the research group Process and Production Optimization. The focus of the research group is to solve real-world problems arising in industrial applications with mathematical optimization. Current research projects are enterprise wide production scheduling in the metals industry, crane scheduling on container terminals, workforce scheduling in the utility industry, and energy management systems for energy-intensive industries. He received his PhD from the University of Kaiserslautern, Germany, in 2008.

Maren Urselmann received the Diploma degree in computer science from the University of Dortmund, Dortmund, Germany, in 2006. Since 2006, she has been a Scientific Assistant with the Process Dynamics and Operations Group, Department of Biochemical and Chemical Engineering, University of Dortmund. Her current research interests include memetic computation in chemical process synthesis.

Stefan Voß is professor and director of the Institute of Information Systems at the University of Hamburg. Previous positions include full professor and head of the department of Business Administration, Information Systems and Information Management at the University of Technology Braunschweig (Germany) from 1995 up to 2002. He holds degrees in Mathematics (diploma) and Economics from the University of Hamburg and a Ph.D. and the habilitation from the University of Technology Darmstadt. His current research interests are in quantitative / information systems approaches to supply chain management and logistics including public mass transit and telecommunications. He is author and co-author of several books and numerous papers in various journals. Stefan Vo serves on the editorial board of several journals including being Editor of Netnomics, Editor of Public Transport, Associate Editor of INFORMS Journal on Computing and Area Editor of Journal of Heuristics. He is frequently organizing workshops and conferences. Furthermore, he is consulting with several companies.

Lutz Westermann is an Optimization Analyst at GAMS Software GmbH. He received his diploma degree in Financial Mathematics and Mathematical Economics from Technical University Braunschweig, Germany.

Rapid Prototyping of Decomposition Algorithms

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Many practical optimization problems cannot be solved by a monolithic model. Decomposition approaches are often the only way out. GAMS is a convenient platform for prototyping such algorithms that require the (repeated) solution of mathematical optimization problems. The GAMS Model Library and other model collections (e.g. see Conejo A J, Castillo E, Minguez R, and Garcia-Bertrand R, Decomposition Techniques in Mathematical Programming, Springer, Berlin, 2006) provide examples for algorithms (e.g. Benders, Dantzig-Wolfe, ...) implemented in GAMS. In certain cases, more traditional programming environments (C++, Python, ...) are better suited for implementing such algorithms. Nevertheless, the handling (generation and solution) of optimization models can become cumbersome in these environments. To combine the power of both worlds GAMS has recently introduced an object oriented API that allows to control GAMS from within different programming languages like C#, Java and Python. The first implementation was done for Microsoft's .NET framework and its numerous programming languages (including C#). The fall 2012 GAMS Release will introduce the Python and Java version of this API. The OO GAMS API offers a seamless integration of GAMS into .NET based IT systems. The API extends the capabilities of GAMS by the addition of the rich features provided by the .NET framework. The powerful in-memory representation of a GAMS model can increase performance when solving a model multiple times with slightly changed data by performing the model creation only once. Convenient data structures allow random access to data as well as data iteration. In short this OO GAMS API allows to build complex algorithms that require the solution of complex mathematical optimization problems.

Risk Conscious Planning under Uncertainty by a Multi-Objective Hybrid MILP/Evolutionary Algorithm

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Many factors, e. g., the future demands, the prices of raw materials, or the yields of the production process are not exactly known in production planning and scheduling. Hence planning decisions must be made based upon information which is incomplete. Often, some decisions can be revised later or can be postponed until more information is available while others must be fixed here and now, with limited information about the future. Decision models with recourse explicitly consider uncertainties, modeled e.g. by scenarios, and the possibility of postponing of correcting some decisions. In the simplest case, two-stage stochastic programming, the decision variables are divided into two sets, the here-and-now decisions which are fixed for all future evolutions, and the recourse decisions which can be made after the uncertainty has been realized, i.e. after it is known which scenario materializes. The scenario-dependent recourse decisions are explicitly considered in the computation of the first-stage decisions.

Decision makers frequently try to avoid the occurrence of very unfavorable situations, e. g. heavy losses. Naturally, they aim at a compromise between expected profit and accepted risk. This can be included into two-stage formulations. In order to solve risk conscious planning problems under uncertainty, a multi-objective evolutionary algorithm is applied together with state-of-the-art MILP optimization of the recourse variables for each scenario. The multi-objective evolutionary algorithm computes the Pareto front of the expected profit and a risk criterion with respect to the here-and-now decisions. The results for a real-world case study from the polymer industry showed that the application of multi-objective evolutionary algorithms is very efficient in solving these very large multi-objective mixed-integer optimization problems. The algorithm computes a set of solution alternatives among which the planner can choose according to his or her degree of risk aversion. For computation times that are comparable to the solution of a single objective problem using a standard MILP solver, the hybrid algorithm computes the whole Pareto front with good accuracy.

A Student Administration and Scheduling System for Federal Law Enforcement Training Centers

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At Federal Law Enforcement Training Centers many students have to graduate different training programs in irregular time periods. For each program exists a predefined standard schedule that determines time and place for all courses of the program. The participants are aggregated to classes and start a certain training program at a certain day and have to get through the program altogether. Since the amount of facility resources is limited and every course requires a certain facility type the main problem is to identify conflicts in terms of overbookings and to minimize them by rescheduling courses to another time slot. The problem distinguishs itself from other scheduling problems by a special type of precedence rules that not only determine the order of some courses but also define a minimum and maximum distance.

The problem can hardly be handled by a monolithic model that allows free scheduling of courses subject to all constraints, so we build up a polylithic model based on Mixed Integer Programming and a heuristic approach. Therefore a master schedule is created by overlaying all the predefined schedules. In the first step we simply identify the resulting conflicts before we allow all courses to move in a small range of days in step 2. Step 3 is a heuristic that iterates over the days with conflicts. We establish different zones around a conflict day in which certain movements of courses are allowed while the rest of the schedule stays unchanged. Thereby the last solution output is always used as the next model input. The solution of realistic instances is massively improved regarding solution time and quality by that heuristic approach compared to the monolithic model.

The Model is implemented in GAMS and uses a MIP solver.

Concurrent Dynamic Optimization of Routing and Sequencing in a Semiconductor Wafer Fab

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A smiconductor wafer fab can be thought of as a stochastic processing network from a logistical point of view. Managers involved in logstic questions at the different levels of the system are interested in the following. Supply chain managers need highly reliable answers about the system response time, i.e. cycle times and delivery dates, when they dynamically put their requests on it. Hereby the network parameters, processing requirements and capacities, as well as the network state at some time t are given. Line managers at the manufacturing floor need to know how to do scheduling and sequencing at the different manufacturing areas so that the overall production goals are fulfilled. Since we deal with a multi-class network with feedback there doesn't exist an optimal control, which is globally optimal at all times. Therefore the lon-run expected (discounted) costs and revenues have to optimized.

It is relatively easy to evaluate these costs and revenues and to find the optimal scheduling parameters for the time-homogeneous case, i.e. when the initial conditions have washed out and the knowledge about market demands ones becomes coarse while its changes occur on a slow time scale, such that the system can follow these slow changes comparatively quickly. This evaluation and optimization can be done via a one-step LP optimization and application of queueing theoretical formulae for steady state queue lengths and waiting times. During the initial phases of network state development, typically a couple of weeks, the noisiness of the system response can be observed as working stock which would not fit to the long term goal, and hence system managers want to force the system in the desired direction.

In this talk a two-stage alogorithm is presented which is used to minimize the costs during the initial phases. Hereby the problem is transformed into one where the time to return to zero levels of translated stocks is minimized. Time is discretized into units which coincide with the time epochs when rescheduling can be done in the real world scenario. At each time epoch in a first step, a decomposition step, the network routing problem is solved for an ensemble of so-called closed machine sets which can be seen as those equipment groups of the overall fab equipment which are connected in the sense that load can be shifted inside each group but not outside of it at some given time epoch. In a second step, a global optimization step, the optimal resource allocations for the aggregated groups of job classes used in Step 1 are split onto elementary job arrival streams, called fluids, in such a way that idleness and makespans in the overall network are minimized. Without rigorous proof it is argued that this also minimizes the time to return to zero, i.e steady state, which is often denoted as relaxation time in queueing theoretical terms.

Xpress-Mosel: Implementing decomposition approaches for concurrent and distributed solving

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Xpress-Mosel is an environment for modeling and solving problems that is provided either in the form of libraries or as a standalone program. Mosel includes a language that is both a *modeling* and a *programming* language combining the strengths of these two concepts. Development and analysis of optimization models is aided by the graphical environment Xpress-IVE, and tools such as the Mosel debugger and profiler, and the Xpress-Tuner. The Mosel libraries provide the neccessary functionality for a tight integration into existing (C/Java/.NET) applications for model deployment. A recent addition to the Xpress suite, the *Mosel remote invocation library (XPRD)*, makes it possible to build applications requiring the Xpress technology that run from environments where Xpress is not installed—including architectures for which Xpress is not available.

Each category of problem comes with its own particular types of variables and constraints and a single kind of solver cannot be efficient in all cases. To take this into account, Mosel does not integrate any solver by default but offers a dynamic interface to external solvers provided as *modules*. Mosel is not restricted to any particular type of solver and each solver may provide its specifics at the user level. Currently available solver modules for Mosel include *mmxprs* that gives access to Xpress-Optimizer for solving Linear, Mixed-Integer, and Quadratic Programming problems, *mmxslp* for defining and solving problems with non-linear constraints via Sequential Linear Programming, and *kalis* for Constraint Programming.

The modular architecture of Mosel can also be used as a means to open the environment to software other than solvers. For example, one Mosel module (*mmodbc*) allows the user to *access databases and spreadsheets* that define an ODBC interface using standard SQL commands. Other modules provide *graphics and GUI functionality*, such as *mmive* for creating graphics in the Xpress-IVE environment, *mmxad* (Xpress Application Developer, XAD) for defining complete graphical applications from within a Mosel model, or the module *mminsight* that establishes the link to the recently released *Xpress-Insight* component for working with optimization applications in distributed, multi-user systems.

The *Mosel Distributed Framework* (module *mmjobs*) implements facilities for handling multiple models, including mechanisms for synchronization and data exchange in memory, thus giving way to an implementation with Mosel of a large range of parallelization schemes and decomposition algorithms. When working with several Mosel models the user may choose to distribute them over several—local or remote—instances of Mosel, including instances running in virtual computing environments (Cloud computing).

This talk discusses several examples of hybrid decomposition algorithms implemented with

Mosel using a combination of different solvers and heuristics in a distributed computing setting. We show how to use the various entry points for user interaction defined by the solver modules (such as callbacks invoked during branch-and-bound search, loading of user solutions into Xpress-Optimizer or automatic linear relaxations in Xpress-Kalis) for the implementation of coarse or tightly integrated hybridization schemes.

References:
For the documentation of Mosel and other components of the Xpress suite please see `http://optimization.fico.com/product-information/`
A comprehensive collection of Mosel model examples is accessible from the Xpress examples database website: `http://examples.xpress.fico.com/example.pl`

The Impact of Algebraic Modeling languages onto the Optimization Community
- Polylithic Modeling and Solution Approaches -

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AMLs have played and still play an important role in the mathematical optimization community and optimization used in industry. In the 1950ies and 1960 Assemeber and Fortran coded LP models were mostly replaced by IBM's matrix generators MPS establishing the standard of industrial model formulations. At that time there was no market for AMLs. But there was no real support for NLP problems. This was the niche for AMLs as they enabled the user to formulate NLP problems, and they supported automatic differentiation, i.e., they symbolically generated the first and second derivative information. After a while, they also became superior in implementing LP models and succeeded MPS. Nowadays, academic research models (developed by scientists) are used to developing and testing solvers, or constructing efficient model reformulations. Domain expert models (developed by analysts) are used within consultancy projects, or feasibility studies. And finally, AMLs often host the models for black box model users doing their operational planning. The AMLs ensure the robustness, stability, and data checks needed in industrially stable software. Furthermore, AMLs accelerate the development and improvement of solvers ranging from Linear Programming to Mixed Integer Nonlinear Programming and even Global Optimization techniques. If a user has an NLP problem implemented in an AML using a local solver to computes its local optimium, it is only a matter of minutes to switch to a global solver such as `BARON` or `LindoGlobal`. Thus, the is a significantly reduced development risk for the user. But also the solver developers can count on a much larger market when their solver is embedded into an AML. The solver technology, in some sense, is now a commodity which allows the users to switch, for instance, from one MILP solver to another one, or play and collect experience with the free Coin-OR solvers. The implementation of polylithic solution approaches described in Kallrath (2011) discussed in detail in this lecture, is possible without huge development efforts. And last but not least, AMLs reduce the project time, make maintenance easier and increasing the lifetime of optimization software.

Based on the Greek *term monolithos* (stone consisting of one single block) Kallrath (2009) introduced the corresponding term *polylithic* for modeling and solution approaches in which mixed integer or non-convex nonlinear optimization problems are solved by a tailor-made methods involving several models and/or algorithmic components. A *monolithic model* is just one model with data, a set of variables and a set of constraints and one solve statement calling a solver, *e.g.*, `CPLEX`, `Gurobi`, or `Xpress`. In contrast, a *polylithic model* contains a set of models which are somehow connected in their data flow of input and output data, *i.e.*, the solution of one model is input to another one. This can be exploited to initialize certain variables, or to provide bounds on them. Examples of polylithic models are decomposition approaches, column generation as in Gilmore & Gomory (1961)] and Branch&Price [see, for instance, Barnhart et al. (1998)] or hybrid techniques [see, for instance, Pochet and Wolsey (2006)] in which constructive heuristics and local search improvement methods are coupled with exact MIP algorithms to produce feasible points and tight lower and upper bounds. Thus, we observe that the sub-models of polylithic models are often connected in such a way that they represent a tailor-made algorithm.

Tailor-made polylithic solution approaches with thousands or millions of solve statement to be executed put an extreme challenge on algebraic modeling languages. Hot-start techniques avoiding that the whole matrix is re-generated become essential.

In this talk we present illustrative examples from the paper and metals industries, scheduling in the process industry, and planning of hydro-thermal plants in the energy industry. Lexicographic goal programming, a useful approach in multi-criteria planning problems, is another example of a polylithic modeling.

References

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Combining Sampling-based and Scenario-based Nested Benders Decomposition Methods

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Nested Benders' Decomposition is a widely used and accepted solution methodology for multi-stage stochastic linear programming problems. Motivated by large-scale applications in the context of hydro-thermal scheduling, in 1991, Pereira and Pinto introduced a sampling-based variant of the Benders' Decomposition method, known as stochastic dual dynamic programming (SDDP). In this paper, we embed the SDDP algorithm into the scenario tree framework, essentially combining the Nested Benders' Decomposition method on trees with the sampling procedure of SDDP. This allows for the incorporation of different types of uncertainties in multi-stage stochastic optimization while still maintaining an efficient solution algorithm. The algorithm is of a polylithic type as thousands of linear programming problems are solved. We provide an illustration of the applicability of our method towards a least-cost hydro-thermal scheduling problem by studying the Panama and the Costa Rica power systems incorporating both electricity demand and inflow uncertainties.

Optimization-based Chemical Process Design by Memetic Algorithms

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Design optimization problems in chemical engineering and in many other engineering domains are characterized by the presence of a large number of discrete and continuous decision variables, complex nonlinear models that restrict the search space, nonlinear cost functions, and the presence of many local optima. The classical approach to such problems are MINLP solvers that work on a superstructure formulation which explicitly represents all design alternatives. The structural decisions lead to a large number of discrete variables and an exponential increase in the computational effort. The mathematical programming (MP) methods which are usually employed to solve the continuous subproblems that arise by fixing the discrete variables provide only one local optimum which depends strongly on the initialization. Thus standard methods may not find the global optimum despite long computation times.

In this contribution we introduce a memetic algorithm (MA) for the global optimization of a computational demanding real-world design problem from the chemical engineering domain. The MA overcomes the problem of getting stuck in local optima by the use of an evolution strategy (ES) which addresses the global optimization of the design decisions. A robust MP solver is used to handle complex nonlinear constraints as well as to improve the individuals of the ES by performing a local search in continuous sub-spaces in an integrated fashion. Only by this hybridization, the best known solutions of several instances of the case study at hand could be found in reasonable computation times. The introduction of structural decisions and additional constrains and discontinuous penalty terms lead only to a moderate increase in the computational effort, i.e. the computational effort is reduced by more than one order of magnitude in comparison to commercially available MINLP solvers.

A Hybrid Algorithm for Production Optimization and Scheduling on a Hot Rolling Mill

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1 Introduction

Production scheduling in the steel industry has been recognized as one of the most difficult industrial scheduling problems. Many different and often contradicting constraints must be taken into account while defining a feasible and, possibly, optimal schedule for the production.

In one of the most typical production configuration, the steel-making process can be roughly subdivided into three parts: the melt shop, where melt steel is produced and cast into semi-finished products (slabs), see e.g. Harjunkoski & Grossmann [?]; the hot rolling, in which slabs are transformed by means of a mechanical and thermal process in the final product (coils, billets, wires,); cold rolling and finishing line operations can achieve customers' specifications for final dimensions, surface quality and mechanical properties. These production steps are highly interconnected; the ideal situation would be to comprise all of them into one optimization model. In our present work, we will focus on the problem of production scheduling on the hot rolling mill.

2 Hot Rolling

The hot strip mill typically consists of several processing stages (reheating furnace, roughing mill, finishing mill, down coiler), on which the slabs need to be processed sequentially in order to be rolled to coils. Strict production rules determine the sequence of the slabs on the hot rolling mill. These production rules are based on physical and metallurgical facts, as well as local experience and quality requirements. Some rules exist in order to avoid wearing or too big temperature changes. Many rules arise from ensuring the product (e.g. surface) quality, for instance through the fact that roll width and thickness changes are limited.

Additionally, orders that are produced in the hot rolling mill need to meet customer due dates, if the product is sold right after the rolling mill, or internal due dates, if the coils are to be further processed in other sections of the steel plant (e.g. cold rolling mill). In this case, the product mix in the hot rolling mill has to also be balanced in order to "feed" different parallel down-stream processes.

Due to the complexity and the variety of plant designs in metals hot rolling only few mathematical programming approaches with applications to real world steel plants have been published. Lopez et al. [?] suggested a heuristic based on Tabu Search, which was successfully applied to Dofasco, a Canadian steel producer, but failed to be applied to other steel plants. Most recently, Zhao et al. [?] applied a two-stage scheduling method to the hot rolling area of Baosteel, China.

3 The Scheduling Algorithm

A production schedule for the hot rolling mill consists of a set of production campaigns (rolling programs), which are composed of a finite number of slabs/coils. The hot rolling scheduling problem consists of creating feasible rolling programs and sequencing them on the plant.

A pure single-step mathematical programming approach can neither capture all the relevant problem aspects nor meet the performance criteria. Therefore, a two-step approach combining heuristic-mathematical programming methods has been developed.

1. Build hot rolling programs,
2. Sequence the built rolling programs.

The programs built in step 1 should be as long as possible and contain as many orders as possible meeting production and quality rules. The procedure to build rolling programs takes into account all rules for allowed width and thickness changes, as well as metallurgical and physical constraints related to subsequent coil compatibilities. The procedure first applies a construction heuristics to form program parts belonging to a certain width class: From a set of orders of a given width class and steel family, a "skeleton" of the program section is built. This "skeleton" contains only the minimal number of coils to fulfill the hard constraints to ensure that the program part is feasible from the production point of view. After this, each part is filled up with other compatible orders to maximize their length. The built program sections (also called program bodies) are thereafter combined into rolling programs by assigning them a cost/profit and by solving a min-cost-flow problem.

The vertices of the graph are the program bodies $b_i, i = 1, \dots, n$, a source s and a sink t. For each body b_i that can be followed by body b_j in a feasible program, we introduce an arc. Moreover, we connect the source s to each body that can be the first body in a program and each body that can be the last body in a program with the sink t.

Each arc connecting two bodies has an associated cost that corresponds to the negated profit of the bodies b_i and b_j and the profit of combining the two bodies to the same program. The arcs connecting the source and the sink have no additional cost. All arcs have capacity of one unit of flow.

The objective is now to minimize the cost of the flow from the source to the sink. In addition to the traditional capacity and flow conservation constraints, we introduce a uniqueness constraint. This constraint ensures that the incoming flow for each body vertex is less than or equal to 1, such that each program body is used at most once. The flow value is determined by solving upfront a max-flow-problem on the same graph.

The built programs are then sequenced, which is a traditional scheduling-type of problem. An MILP formulation of the problem is proposed taking into account due date and production mix constraints. The formulation is an extension of the slot-based approach by Pinto and Grossmann [?].

4 Benefits

Using the described approach for building hot rolling programs, we can ensure that all production requests that were not included in a program can neither form a valid program by themselves nor be added to already built programs.

The concept of building skeletons and filling the skeletons to form program parts ensures that we always consider the most valuable production requests first. Valuable production requests are e.g. coils with early due dates or coils with minimal finishing thicknesses.

Moreover, the utilization of the minimum cost flow problem for composing program parts to full programs ensures that the most valuable program parts are selected and that the combination of program parts is optimal in terms of similar due dates and common steel properties. Valuable program parts are, e.g., bodies that contain a high number of valuable coils and that form a long sequence of production requests in kilometers. Therefore, our approach results in a feasible rolling program meeting the quality requirement, while maximizing the number of rolled production requests and the value of the production requests, as well as minimizing the work roll changes and the usage of waste material.

Considering production requests of one month (about $2000-5000$ coils), the program building procedure takes less than 30 seconds of computational time. The second step, sequencing the programs, requires more computational effort. Restricting the computational time of the sequencing MILP to 120 seconds yields sufficiently good sequences. Therefore, we can ensure a total computational time of strictly less than three minutes.

Finally, since we consider orders for up to several weeks (e.g., production requests in next month's order book), the scheduling department gains a better insight into the order book and the additional material needed to fill the gaps in the order portfolio. The visualization of the production plan for the next weeks and the highlighting of key performance indicators enable the schedulers to plan and react more accurately to the business plan and, therefore, improve the productivity of the plant.

This presentation is based on a joint work with Iiro Harjunkoski, ABB Corporate Research, Ladenburg, Germany, and Matteo Biondi, ABB S.p.A, Genova, Italy.

References

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Matheuristic Approaches for Solving Reliability Problems

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In this paper a hybrid algorithm for the Redundancy Allocation Problem is presented. The problem tackled is the optimal allocation of redundant components within series-parallel systems. We present an algorithm that deals with the *classical* formulation, where at least one component per subsystem must be included in the final configuration, as well as the k-out-of-n formulation, in which at least k components per sub- system must be included in the final network configuration. We propose a three-phase scheme in which the Cross Entropy Method, the Corridor Method and a Dynamic Programming-based scheme are effectively intertwined. Computational results on well-known benchmark instances as well as on randomly generated large scale instances are presented, proving the effectiveness and robustness of the proposed algorithm. All benchmark instances are solved to optimality by the proposed scheme in less than five seconds on a regular workstation. Additional consideration is given to the connection of redundancy allocation, reliability and some knapsack problems. .