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 joint Workshop of the GOR working groups "Practice of the mathematical optimization" and "Supply Chain Management" in the House of German Physical Society in Bad Honnef (Physikzentrum Bad Honnef, Hauptstr. 5, 53604 Bad Honnef, http://www.pbh.de). This meeting's topic is

Scheduling in the Process Industry

The workshop starts on **20.11.2008** at **10:00** and ends on **21.11.2008** at about **17:45**.

The working language will be preferably English, since some speakers 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 10.10.2008. The latest information on the meeting is available on the homepage of the GOR (http://www.gor-ev.de/ or https://gor.uni-paderborn.de/Members/AG06/) under the category *Arbeitsgruppen*.

Yours sincerely,

Josef Kallrath (GOR AG) & Alexander Lavrov (ITWM Kaiserslautern) & Herbert Meyr (TU Darmstadt)

Scheduling in the Process Industry

Scheduling in the process industry is a complicated task. This statement applies to the chemical, pharmaceutical, food and refinery industries as well as the metals and steel industry. In multi-product batch and continuous chemical plants, for instance, different products are manufactured via the same or similar sequence of operations by sharing available pieces of equipment, intermediate materials, and other production resources. They have long been accepted for the manufacture of chemicals that are produced in small quantities and for which the production process or the demand pattern is likely to change. The inherent operational flexibility of this type of plant provides the platform for great savings reflected in a good production schedule. The Chemical Process Industry alone is one of the largest sectors of the world economy, with annual revenues in excess of $4 Trillion. 70% of this or $2.8 Trillion consists of raw material and processing costs. A small savings in this can unleash Billions of $'s of hidden profits.

A few commercial software packages for addressing scheduling problems in the process industry exist. However, they have not yet reached the systematic and well accepted framework as mixed integer programming has reached for planning in the process industry. This workshop will give an overview about the state-of-the art technologies illustrated by real-world applications.

In 14-15 talks, each approx. 40-45 minutes, experts from practice, research institutions or software companies, will present selected problems and the corresponding solutions.

Particular attention will be paid to contributions from industry and industry research solving the problems in theirs field using scheduling techniques. Confirmations for their talks have been obtained from the following speakers:

Dr. Pavel Borisovski (Omsk State Technical University, Omsk, Russia)
Dr. Ron Coxhead (Honeywell Hi-Spec Solutions, Wiesbaden, Germany)
Dr. Anton Eremeev (Omsk Branch of Sobolev Institute of Mathematics SB RAS, Omsk, Russia)
Prof. Dr. Christodoulos Floudas (Dept. of Chemical Engineering, Princeton University, Princeton, NJ, USA)
Dr. Iiro Harjunkoski (ABB Forschungszentrum Deutschland, Ladenburg, Germany)
Dr. Axel Hecker (Mathesis GmbH, Mannheim, Germany)
Dr. Franz Höfferl (OMV, Vienna, Austria)
Prof. Dr. Josef Kallrath (BASF SE, Ludwigshafen, Germany)
Erwin Kalvelagen (Amsterdam Optimization Group, Den Haag, The Netherlands)
Dipl.-Math. Steffen Rebennack (University of Florida, Gainesville, FL, USA)
Dr. Luc Schepens (OM Partners, Köln, Germany)
Prof. Dr. Christoph Schwindt (TU Clausthal, Germany)
Dr. Christoper Sürie (SAP Deutschland AG & Co. KG, Waldorf, Germany)
Dr. Jochen Till (BASF SE, Ludwigshafen, Germany)
Prof. Dr. Norbert Trautmann (University of Bern, Switzerland)
Björn-Ragnar Weber (Boehringer Ingelheim Pharma GmbH & Co KG, Ingelheim / Rhein, Germany)

In particular, the following thematic fields will be addressed:

- Chemical industry
- Pharmaceutical industry
- Refineries

We expect an interesting overview of „Scheduling in the Process Industry", reflecting modern requirements, possibilities, and limitations. Part of the official program is a visit and a guided tour through the Adenauer Haus in Rhöndorf (on Thursday afternoon, 15:00).

The official opening is at 10:00 on 20.11.2008. The conference dinner takes place at 18:45 on the same day. The closure of the event is scheduled for 21.11.2008, at about 17:45.

Further contributions are welcome if they describes techniques or problems relevant for scheduling in the process industry. In particular, we look forward for practice-oriented application examples and case studies where scheduling problems have been solved rigidly using mathematical optimisation methods rather than using pure heuristics.

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81. Sitzung der GOR Arbeitsgruppen
Praxis der Mathematischen Optimierung & Supply Chain Management

Scheduling in the Process Industry

Physikzentrum, Bad Honnef, November 20 & 21, 2008

Thursday, Nov. 20 - 2008 : 10:00 – 18:35

10:00-10:10 **Opening and Welcome Session** (J.Kallrath & H. Meyr)

10:10-10:25 **Victor Gomer** Physikzentrum, Bad Honnef, Germany
Information on the Conference Center

10:25-11:10 **Ronald Coxhead** Honeywell Process Solutions, Wiesbaden, Germany
An Overview of the Development of Continuous Process Scheduling

11:15-12:00 **Franz Höfferl** OMV Refining & Marketing GmbH, Vienna, Austria
A Dynamic Programming Extension to the Steady State LP

12:00-13:15 ---------- Lunch Break ----------

13:15-13:45 **Susumu Ikenouye** Ike Ltd., Tokyo, Japan
Aspects of Process Industry Scheduling in Japan

13:45-14:20 **Pavel A. Borisovsky** Omsk State Technical University, Omsk, Russia
A Hybrid Method for Multi-Product Continuous Plant Scheduling Based on Decomposition Approach and Genetic Algorithms

14:20-15:15 **Axel Hecker** Mathesis GmbH, Mannheim, Germany
"Booking World" versus "Physical World": Challenges in Linking Optimization to SAP APO

15:15-17:00 ---------- Coffee Break / Visit & Guided Tour: Adenauer Haus ----------

17:00-17:45 **Steffen Rebennack** University of Florida, Gainesville, USA
Optimal Tank Design: A Nonconvex MINLP Formulation

17:45-18:30 **Christopher Sürie** SAP Deutschland AG & Co. KG, Waldorf, Germany
Tank scheduling in SAP SCM - Modeling Tricks and New Features

18:30-19:20 **Christodoulos A. Floudas** Princeton University, NJ, USA
Integrated Operational Planning and Medium-Term Scheduling of a Large-Scale Industrial Batch Plant

19:30 - **Conference Dinner** – Buffet; get-together in the wine-cellar
Celebrating the 81th Meeting of our GOR Working Group

Friday, Nov. 21 - 2008 : 09:00 – 17:45

09:00-09:45 **Norbert Trautmann** Universität Bern, Switzerland
Sequential Batching and Scheduling of Multi-stage Multi-product Batch Plants

09:50-10:35 **Christoph Schwindt** Clausthal University of Technology, Germany
A Closed-Loop Heuristic for Continuous Process Scheduling

10:35-10:50 ---------- Coffee Break ----------

10:50-11:35 **Anton V. Eremeev** Omsk Branch of Sobolev Inst. of Mathematics Omsk, Russia
MIP-based Heuristics for Scheduling Batch Production with Shifts

11:40-12:25 **Jochen Till** BASF SE, Ludwigshafen, Germany
New Hybrid Evolutionary Algorithms for Chemical Batch Scheduling under Uncertainty

12:30-13:30 ---------- Lunch Break ----------

13:30-14:05 **Marc Scherens** OM Partners, Cologne, Germany
Scheduling Optimization of different value chains at BASF CZ (Intermediates division) in Ludwigshafen

14:10-14:50 **Erwin Kalvelagen** Amsterdam Optimization Group, The Netherlands
Implementation of some Practical Scheduling Models, Tales from theTrenches

14:55-15:20 ---------- Coffee Break ----------

15:20-16:10 **Iiro Harjunkoski** ABB Forschungszentrum Deutschland, Ladenburg, Germany
Solving Industrial-Size Scheduling Problems

16:10-17:00 **Björn-Ragnar Weber** Böhringer Ingelheim Pharma GmbH, Ingelheim, Germany
A Heuristic for Generating Production Plans for Manufacturing Active Pharmaceutical Ingredients

17:00-17:45 **Panel Discussion - Particpants**
Coxhead, Floudas, Hecker, Höfferl, Ikenouye, Kallrath, Sürie
The Future of Scheduling in the Process Industry: Challenges and Opportunities

17:45-17:55 **Final Discussion – End of the Workshop**

The Speakers and the Particpants of the Panel Discussion

Pavel Borisovsky is a lecturer at Omsk State Technical University teaching computer programming and Operations Research. He received his PhD in 2005 on theory and applications of evolutionary algorithms. Now he is working on joint research project with BASF SE on application of MIP methods to solving production scheduling problems.

Ronald Coxhead is an independent consultant and Principal Consultant associated with Honeywell Advanced Process Solutions' Centre of Excellence for Planning and Scheduling, (previously Bonner & Moore Associates) located in Wiesbaden, Germany.

He has over 35 years of industrial experience world-wide in the design and application of planning, backcasting and scheduling models and systems for refinery and petrochemical processes. Bonner & Moore was one of the original instigators of planning systems based on NLMIP optimization as well as rule based scheduling for continuous processes, and has given birth through its former employees to many of the concepts and systems available today from other sources.

In the context of the GDOR conference, he will present the development of solutions for continuous process scheduling seen from the perspective of hydrocarbon processing with an occasional look at batch processes as noted from experience in food, automobile and plastics production.

Ronald Coxhead holds a Ph.D. degree in Industrial Mathematics.

Anton Eremeev is docent at Omsk Branch of Sobolev Institute of Mathematics, Siberian Branch of Russian Academy of Sciences (Omsk, Russia). His research interests are in Research interests: evolutionary algorithms and hybrid schemes, heuristics and software for production line optimization, approximation algorithms for the NP-hard problems, set covering and vertex covering problems, local search and fitness landscape analysis, and optimization problems in wholesale electricity markets. During the years 2004 to 2008 he has been involved in the following industrial projects: prototyping financial transmission rights for Russian wholesale electricity market and survey of international experience, methods for hubs design in wholesale electricity market, and the development of hybrid methods for approximate solutions of large-scale MIP problems in scheduling for BASF SE, Ludwigshafen, Germany.

Christodoulos A. Floudas is the Stephen C. Macaleer '63 Professor in Engineering and Applied Science, Professor of Chemical Engineering at Princeton University, Associated Faculty in the Program of Applied and Computational Mathematics at Princeton University, Associated Faculty in the Department of Operations Research and Financial Engineering at Princeton University, and Faculty in the Center for Quantitative Biology at Princeton University. He earned his B.S.E. in 1982 at Aristotle University of Thessaloniki, Greece, completed his Ph.D. in December 1985 at Carnegie Mellon University and joined Princeton University as a Faculty Member in February 1986. In July 1991 he was promoted to Associate Professor and in July 1994 to Professor. He held Visiting Professor positions at Imperial College, England (Fall 1992); Swiss Federal Institute of Technology, ETH, Switzerland (Spring 1993); University of Vienna, Austria (Spring 1996); the Chemical Process Engineering Research Institute (CPERI), Thessaloniki, Greece (Fall 1998); the Institute of Mathematics and its Applications (IMA), University of Minnesota (Spring 2008); and Chemical Engineering and Materials Science, University of Minnesota (George T. Piercy Distinguished Visiting Professor, 2008).

Professor Floudas is a world-renowned authority in mathematical modeling and optimization of complex systems at the macroscopic and microscopic level. His research interests lie at the interface of chemical engineering, applied mathematics, and operations research, with principal areas of focus including chemical process synthesis and design, process control and operations, discrete-continuous nonlinear optimization, local and global optimization, and computational chemistry and molecular biology. He is the recipient of numerous awards for teaching and research that include the NSF Presidential Young Investigator Award, 1988; the Engineering Council Teaching Award, Princeton University, 1995; the Bodossaki Foundation Award in Applied Sciences, 1997; the Best Paper Award in Computers and Chemical Engineering, 1998; the Aspen Tech Excellence in Teaching Award, 1999; the 2001 AIChE Professional Progress Award for Outstanding Progress in Chemical Engineering; the 2006 AIChE Computing in Chemical Engineering Award; and the 2007 Princeton University Graduate Mentoring Award.

Iiro Harjunkoski received his Ph.D. at the Process Design Laboratory of bo Akademi University in 1997, and worked as a post-doc at bo Akademi University and Carnegie Mellon University (1999-2001), after which he joined ABB Corporate Research Germany in 2001. He is currently Senior Principal Scientist in the area of Process- and Production Optimization. His main focus is on methods for modeling and solution of scheduling and combinatorial optimization problems and their applications in the process industries.

Axel Hecker is one of three managing directors of Mathesis GmbH, Mannheim (Germany), founded in 1999. Mathesis is engaged in different fields of software development and support, especially mathematical optimization and communication in SAP environments. Before founding Mathesis, he was working for BASF AG Ludwigshafen (Germany), where he provided mechanisms and frameworks for retrieving data to be used in optimization applications. His background is not primarily technical: He studied German Literature and Language as well as Philosophy and History at Heidelberg University and received his PhD in that subject, before he moved towards the computation field in the mid 80s. His main topic of work is the development and implementation of data translators that link ERP systems like SAP with automated scheduling and planning tools.

Franz Höfferl was born in Austria 1950. He studied physics at university of Vienna, and obtained his PhD in 1978 with a dissertation entitled "Research on metallurgical values by subthermal neutrons", a nuclear-physical application of non-invase material analysis. He worked as physicist for projects of the Austrian Academy of Sciences. In 1979 he joined OMV - building and maintaining LP models. Since 1995 he is the head of the department "Operations Research". His main topic of work is the development of dynamic optimization algorithms for crude selection&scheduling and for scheduling of OMV refineries.

Susumu Ikenouye is the president of Ike Ltd. founded 2000 and is a consultant of development practical mathematical optimization planning system for process industry. Before establishing Ike, he was working for Fuji Oil, an oil refining company, for 30 years and had been in responsibility of computerized application systems in every functions of company. His current focus is overall management system including mathematical optimization functions for planning and scheduling for oil process industry.

Erwin Kalvelagen is an independent consultant. His experience includes providing services related to mathematical programming, statistical and economic modeling for industry, institutes and government agencies. He previously worked for GAMS Development, Statistics Netherlands, TNO Applied Physics Laboratory and the Free University Amsterdam.

Steffen Rebennack is a PhD student in Industrial & Systems Engineering at the University

of Florida, USA. Prof. Dr. Pardalos is his thesis PhD adviser. Steffen Rebennack got his diploma degree in 2006 in mathematics from the University of Heidelberg, Germany. His research interests are in global optimization, modeling, decomposition methods, power systems modeling, power systems optimization and combinatorial optimization.

Christoph Schwindt is professor of operations management at Clausthal University of Technology, Germany. He received his PhD in operations research at the University of Karlsruhe in 1997. His research interests are in combinatorial optimization and applications, with special focus on project scheduling, process planning and scheduling, supply chain management, and distributed decision making.

Christopher Sürie works in the field organisation of SAP Deutschland AG & Co. KG. He provides expert consulting to customers globally in the area of SCM optimization (SAP SCM) and transportation management (SAP TM). His focus are the planning engines inside SAP applications in the area of production and transportation. Prior to joining SAP he worked as a research assistant at TU Darmstadt. There he earned a PhD with a thesis aboout production planning in the process industry.

Jochen Till received his PhD in 2007. For his PhD thesis he developed new hybrid evolutionary algorithms for stochastic programming in chemical batch scheduling. Since 2007 he is a Senior Process Engineer at BASF SE, Ludwigshafen, Germany. His interests and experiences are simulation and optimization techniques for improving the design and operation of real-world engineering problems.

Norbert Trautmann received the Business Engineering, PhD and Habilitation degrees from the University of Karlsruhe (Germany) in 1997, 2000, and 2004, respectively. His PhD thesis on scheduling of chemical batch processes has been awarded by the German Operations Research Society. Since 2005 he is an Assistant Professor in Quantitative Methods at the Department of Business Administration of the University of Bern (Switzerland). Norbert Trautmann has published about resource-constrained project scheduling and about short-term planning of chemical batch processes in European Journal of Operational Research, OR Spectrum, International Journal of Production Research, and International Transactions in Operational Research.

Björn-Ragnar Weber studied business engineering at TU Darmstadt and received his diploma in 2004. Hew was then employed as a PhD student at Boehringer Ingelheim Pharma GmbH & Co. KG in corporation with the University of Hamburg. For his PhD thesis he developed a heuristic generating production plans for the manufacturing of active pharmaceutical ingredients which makes partial use of mathematical programming. He currently works in the production and engineering department of Boehringer Ingelheim Pharma GmbH & Co. KG where he amongst other projects implements and extends the heuristic.

A Hybrid Method for Multi-Product Continuous Plant Scheduling Based on Decomposition Approach and Genetic Algorithm

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The starting point of our work is the short-term and medium-term scheduling approach developed by Shaik et al. (2007) for an industrial large-scale polymer compounding plant comprising several processing and storage units operating in a continuous-mode for producing hundreds of different products over one month time horizon.

Here we propose a hybrid method for medium-term scheduling of such large-scale industrial plants with continuous processes, combining a decomposition approach, a genetic algorithm and a constructive MIP-based heuristic. In the decomposition, two subproblems are solved using a rolling horizon approach. An upper level model is used to find a reduced set of products to be considered for solving the lower level short-term scheduling problem. At the lower level, a short-term scheduling MIP-model with unit-specific event-based continuous-time representation is used. A heuristic solution to the lower level problem is found using a constructive Moving Window heuristic guided by a genetic algorithm. The genetic algorithm is applied for finding efficient utilization of critical units in the lower level problem, which is simplified as lot-sizing and scheduling problem on unrelated parallel machines (Dolgui, Eremeev, Kovalyov, 2007). An improved performance of the proposed method is demonstrated

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on a real case of a large-scale plant.

The research was supported in part by Russian Foundation for Basic Research, grant 07-01-00410.

References:

M. A. Shaik, C. A. Floudas, J. Kallrath and H.-J. Pitz, 2007, *Production Scheduling of a Large-Scale Industrial Continuous Plant: Short-Term and Medium-Term Scheduling*, in: V. Plesu and P.S. Agachi (Editors), 17th European Symposium on Computer Aided Process Engineering – ESCAPE17.

A. Dolgui, A. Eremeev, M. Kovalyov, 2007, *Multi-product lot-sizing and scheduling on unrelated parallel machines.* Research Report 2007-500-011, Ecole des Mines de Saint-Etienne.

An Overview of the Development of Continuous Process Scheduling

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Continuous Process Scheduling is a difficult problem because it combines quality and quantity for each raw material and product together with lot size determination. The problem is event based, e.g. arrival or loading of ships or the usage of pipelines.

Many attempts have been made to grasp this problem mathematically. All paradigms, starting with the early 1960s were promising. Most failed because the scheduler could not interpret the resultant schedule. This is still true today though graphical methods have improved the quality of the presentation to a scheduler, who is very often under considerable pressure.

This paper will try to map the development of methods concentrating on refinery and petrochemical applications. The methods range from calculation sheets to rule based systems and the return, in the current decade, to the concept of event based NLMIP approaches.

MIP-based Heuristics for Scheduling Batch Production with Shifts

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In this paper, we consider a single machine batch scheduling problem: it is required to minimize the makespan criterion, taking into account that the machine operates on shift basis, so that all jobs initiated during a shift must be completed within this shift. A partial order on the set of jobs is given. Some subsets of jobs are incompatible for simultaneous batch production, some must be executed simultaneously in a batch, and some must be grouped into same shift. The problem has a lot in common with the Transfer Line Balancing Problem (Dolgui et al, 2006).

We propose a MIP-based greedy randomized adaptive search procedure (GRASP) and a genetic algorithm (GA) for this problem using MIP formulation. The solution construction and the local improvement stages of GRASP are based on solving sub-problems of smaller size. The same solution construction method is used for initialization of the first population in the GA. The crossover and mutation in the GA are combined in MIP-recombination operator (Borisovsky, Dolgui, Eremeev, 2007).

Both algorithms are implemented in GAMS using CPLEX MIP solver and compared on randomly generated instances. The results of computational experiments indicate that on the large-scale problems the methods proposed are in advantage to the pure CPLEX solver in finding the high quality solutions.

The research was supported in part by Russian Foundation for Basic Research, grant 07-01-00410.

References:

P. Borisovsky, A. Dolgui, A. Eremeev, 2007, *Genetic algorithms for a supply management problem: MIP-recombination vs greedy decoder.* To appear in European Journal of Opera-

tional Research. doi:10.1016/j.ejor.2007.06.060.

A. Dolgui, B. Finel, N. Guschinsky, G. Levin and F. Vernadat, 2006, *MIP approach to balancing transfer lines with blocks of parallel operations.* - IIE Transactions, vol. 38, pp. 869-882.

Integrated Operational Planning and Medium-Term Scheduling of a Large-Scale Industrial Batch Plant

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The operational planning and the medium-term scheduling of a multipurpose and multiproduct batch chemical plant are interrelated activities dealing with the allocation of plant resources. Due to their disparate time scales, however, the effective integration of planning and scheduling has proven to be a formidable task. The lack of an integrative framework for planning and scheduling will invariably cause the planning model to provide unrealistic production targets to the scheduling level leading to the misallocation of plant resources. In response to this issue, a novel framework for the integration of planning and scheduling for a multipurpose and multiproduct batch plant is presented. The framework entails integrating a novel planning with production disaggregation model with a medium-term scheduling model through a forward rolling horizon approach.

Solving Industrial-Size Scheduling problems

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Many academic scheduling approaches work well for small-scale example problems, but relatively little attention has been paid on how to scale up a solution. Also, the integration aspect is often left out from the scope. This talk discusses some of the challenges when applying a theoretical model to industrial scale, including some examples.

"Booking World" versus "Physical World": Challenges in Linking Optimization to SAP APO

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This presentation is less focused on optimization as such, but rather on data and interpretation aspects that come up when you actually try to link some existing optimization model to a data delivery system like SAP APO.

Background is the implementation of a scheduler in different BASF plants located in Ludwigshafen/Germany: Some SAP APO user can call the scheduler, which has been specifically developed for these plants, directly from his or her standard SAP APO GUI. Details of this tight link between SAP APO and the scheduler will be outlined.

Subject of this presentation are the conceptual hurdles that have to be overcome: SAP APO can be regarded as a booking system that tries to keep track of all events relevant to the "Booking World" in order to keep all spots informed on what the plant does at certain points in time. On the other side, the scheduler typically follows a very rigid time and mass balance scheme, constrained by causal rules dominating the "Physical World". As it turned out, in many cases, there were significant discrepancies between the two: Process descriptions that seemed perfectly consistent with organizational rules, would not fit, or at least not exactly fit with physical rules - provoking the optimizer to become infeasible.

The target of this presentation is a) to make people more aware of this type of discrepancies and b) make proposals on how to deal with them more smoothly on both sides involved.

A Dynamic Programming Extension to the Steady State LP

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Standard LPs, widely used for planning in the processing industry, are powerful tools for making economic decisions, but do not cover time relationships inside the planning time-frame. To include sequence-dependent issues within the optimization process, an algorithmic extension to the LP was developed. DPX (Dynamic Programming Extension) is used to solve a whole class of problems that are dynamic in time.

DPX applications for refinery scheduling and crude scheduling will be presented and discussed.

Implementation of some Practical Scheduling Models, Tales from the Trenches

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We will discuss two scheduling models: a parallel machine scheduling problem of unrelated machines with sequence dependent set-up times for the chemical industry and a power generation and transmission investment planning model for New Zealand. Both models have been developed in GAMS and Cplex. We will present lessons learned, and illustrate some of the things that worked and also some of the obstacles that were encountered. Besides development of the mathematical models we will also discuss some surrounding issues such as data extraction and verification, reporting and development of heuristic algorithms to help improve performance of the core models.

Scheduling Optimization of different value chains at BASF CZ (Intermediates division) in Ludwigshafen.

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In 2004, BASF CZ in Ludwigshafen reviewed its supply chain capability and decided to make dramatic changes to its planning philosophy to move from volume based to value based planning.

In this presentation, Marc Scherens, Director Customer solutions at OM Partners will explain the modeling and mathematical techniques that were used to achieve the following objectives:

1. Integrated value chain optimization over different production facilities;

2. Margin maximization rather than pure volume calculation supported by scenario-management;

3. Transparency in steering the whole planning process (roles & responsibilities, KPIs, processes);

4. Perfect integration between APS-system and SAP R/3, elimination of isolated Excel-planning-tools.

Optimal Tank Design: A Nonconvex MINLP Problem

Steffen Rebennack[1], Josef Kallrath[2] and Panos M. Pardalos[1]

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We discuss a tank design problem for a multi product plant, where the optimal cycle time and the optimal campaign size are unknown. A mixed integer nonlinear programming (MINLP) formulation is presented, where non-convexities are due to the tank investment cost, storage cost, campaign setup cost and variable production rates. The objective of the optimization model is to minimize the sum of the production cost per ton per product produced. The model is decomposed into event points and solved with the global solver LINDOGlobal in the modeling language GAMS. We present some preliminary results and address open questions.

A Closed-Loop Heuristic for Continuous Process Scheduling

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We consider the short-term scheduling of multistage continuous multiproduct plants. In the literature this problem is generally modeled as a monolithic mixed-integer linear or nonlinear program. In this paper we follow a closed-loop decomposition approach which starts from a partition of the problem into an operations planning and an operations scheduling problem. The operations planning problem consists in fixing the operating conditions of the tasks and can be formulated as a nonlinear program of moderate size. The solution to the operations planning problem provides a set of operations, which have to be scheduled on the processing units of the plant. For solving this operations scheduling problem we present a novel mixed-integer linear programming formulation as well as a fast priority-rule based scheduling method. Having computed a feasible production schedule, we return to the operations planning phase, where we re-optimize the operating conditions in such a way that we can guarantee the existence of a feasible solution to the operations scheduling problem. We proceed with scheduling the operations again and iterate the planning and scheduling phases until a fixed-point solution has been reached. The new method is able to find good feasible schedules for complex benchmark instances within less than one minute on a standard PC.

This is joint work with Sascha Herrmann and Hanno Sagebiel (TU Clausthal)

Tank scheduling in SAP SCM - Modelling Tricks and New Features

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In process industries, tank scheduling can be a very critical part of the production planning process, because in many facilities, the number of tanks are limited and usually tanks can only be used for one product at a time. SAP SCM offers some functionalities in the area of tank scheduling in its production planning / detailed scheduling (PP/DS) module. In this talk, it is shown how the tank scheduling requirements have been met for a client using several modelling tricks. The second part of the talk will cover the new features in the area of tank scheduling to be included in the upcoming SCM release.

New Hybrid Evolutionary Algorithms for Chemical Batch Scheduling under Uncertainty

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Two-stage stochastic mixed-integer linear programs with discrete scenarios (*2S-MILP*s) that arise in chemical batch scheduling under uncertainty usually give rise to large scale optimization problems. The large problems cannot be solved easily without incorporating decomposition methods or problem specific knowledge.

A new hybrid evolutionary algorithm framework is proposed. Based on stage-decomposition, an evolutionary algorithm (*EA*) performs the search on the first-stage variables while the decoupled second-stage scenario problems are tackled by a *MILP* solver. The approach is evaluated for a real-world scheduling problem of an industrial polymer production batch plant with uncertainties in the demand and in the plant capacity.

In the beginning a generic hybrid *EA* for *2S-MILP*s is realized. Then it is extended by three elements that are customized to the example problem. First, a computationally cheap specific initialization scheme is developed. Second, a reduction of the search space by two orders of magnitude is proposed. Third, a problem specific *EA* with mutation operators is developed based on the concept of 'minimal moves'. The specific *EA* is more robust than the generic one and has better abilities to explore the complete search space.

The performance of the hybrid *EA*-based approaches is compared to the performance of the state-of-the-art *MILP* solver *CPLEX* and to that of the state-of-the-art decomposition based *2S-MILP*-algorithm of Carøe und Schultz (1999), *DDSIP*. The latter *2S-MILP*-algorithm required a problem specific adaptation to provide any other than the initial solution, whereas the generic *EA* converged without modifications. With problem specific adaptations, *DDSIP* and the *EA*-based approaches performed better than *CPLEX* in most cases. The scale-up behavior of the *EA* with respect to the number of scenarios is approximately linear, whereas that of *CPLEX* and *DDSIP* is significantly stronger than linear. For *2S-MILP*s with a relatively high number of scenarios, or when relatively good solutions are needed quickly, the *EA* based approach is preferable.

This presentation provides a case study for the design of engineered algorithms for mathematical programming. The presented algorithms use problem insights with combinations of various solution techniques.

This work was compiled at the Process Dynamics and Operations Group (DYN) of Prof. Dr.-Ing. Sebastian Engell at the Technische Universität Dortmund.

Sequential Batching and Scheduling of Multi-stage Multi-product Batch Plants

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We deal with the short-term planning of batch production on multi-stage, multi-product plants. Such a plant consists of processing units and storage facilities. On each processing unit, a set of transformation processes can be carried out that add value by means of chemical of physical transformation of material. Between the execution of dirent processes and (in some cases) before an idle time, the processing unit must be cleaned. Raw material, nonperishable intermediates, and final products can be stored in the storage facilities, whereas perishable intermediates must be consumed immediately after production. Material flows are linear, divergent, convergent, or even cyclic. For some processes, the proportions of the input products or the output products are flexible. We deal with the case of batch production, which means that all inputs must be filled into the processing unit used before carrying out a process, and the output cannot be removed from the unit before the process has been completed. The batch size is limited by the minimum filling level and the volume of the processing unit. We assume that the process duration depends on the unit used, but not on the actual batch sizes. The problem discussed in this talk is to compute a feasible schedule with minimum makespan such that some given primary requirements for the final products are fulfilled.

This problem decomposes into a batching problem and a scheduling problem. The variables of the batching problem are the number of batches for each process, the size of each batch, and the proportions of the input or output products of each batch; solving the scheduling problem assigns a start time to the processing of each batch. Most of the approaches discussed in the literature address both problems simultaneously. In contrast, we propose to solve the batching and the scheduling problem sequentially.

In our talk, we present a new formulation of the batching problem as a mixed-integer linear program and a novel priority-rule method for the scheduling problem. Eventually, we report the results of an experimental performance analysis. The set of problem instances used has been generated by varying the primary requirements for the final products in several sample production processes discussed in the literature. It has turned out that optimal or near-optimal schedules are obtained within short CPU times.

This is joint work with Rafael Fink and Christoph Schwindt (TU Clausthal).

A Heuristic for Generating Production Plans for Manufacturing Active Pharmaceutical Ingredients

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Manufacturing of active pharmaceutical ingredients is a multi-stage batch process with a number of additional constraints regarding the length of campaigns, time-limits on consecutive process tasks (e.g. zero-wait), recurring deterministic delays in the material flow (e.g. due to quality control or transport), and cyclic material flows.

A heuristic has been developed to generate detailed medium– to long–term production plans for a real world case. It consists of a stochastic construction heuristic determining feasible campaigns and a modular improvement heuristic (making use of a MIP model). The objective is to minimize costs including penalty costs for late delivery and safety stock violations.