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DORS Formanden har ordet

Velkommen til endnu et nummer af ORbit! I sidste nummer blev det kort nævnt, at der var blevet valgt en ny bestyrelse, men hvad ikke blev nævnt var, at Julie Jespersen Groth ved sidste generalforsamling desværre valgte at træde af som formand for DORS. Julie har ydet en kæmpe indsats for DORS og der skal lyde en stor tak herfor! Valget som ny formand tilfaldt mig, og min opgave er nu at fortsætte de mange gode tiltag, som Julie og den daværende bestyrelse har fået sat i gang samt at sikre at den gode ånd i DORS opretholdes. Jeg ser frem til opgaven og vil gøre mit bedste!

En af de vigtigste opgaver for DORS er at bidrage til opretholdelsen af det stærke netværk blandt operationsanalytikere, og hertil er forskellige arrangementer både i og udenfor DORS en vigtig bestanddel. Et af de helt store arrangementer, Nordic Optimization Symposion 4, afholdes i Århus 30.09 - 02.10. Derudover afholdes der OR-dag i Århus d. 03.11, og sidst men ikke mindst afholdes ultimo januar 2011 det årligt tilbagevendende seminar »Applications Of Optimization« (AOO) i København. Læs mere om OR-dagen i Århus i dette nummer. Mere information om AOO udsendes senere på året.

Udover planlægning af arrangementer arbejder vi i bestyrelsen lige nu hårdt på en kraftig sanering af vores medlemshåndtering. Dette omfatter blandt andet en ny medlemsdatabase samt på sigt muligheden for tilmelding til PBS i forbindelse med kontingentomkrævning. Og apropos dette så vil jeg hermed benytte lejligheden til at gøre opmærksom på en lille justering. Kontingentopkrævningen for 2010 vil blive sendt i efteråret, da denne opkrævning er bagudrettet, men for 2011 og fremover vil opkrævningerne være fremadrettede, og vil således blive udsendt i løbet af foråret kort efter generalforsamlingen. Man kan derfor forvente to opkrævninger tæt på hinanden.

Som en slutbemærkning er det med stor glæde at vi kan byde velkommen til A. P. Møller – Mærsk A/S som nyt firmamedlem af DORS.

God læselyst!

Tor Justesen
Formand for DORS

Aktuelt om DORS september 2010

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Bästa SOAF-medlemmar!

Med kort varsel fick våra danska OR-vänner i DORS möjlighet att skapa ett extra nummer av ORbit i samband med konferensen Nordic Optimization Symposium. Vi är glada att de tog den chansen, och att SOAF får vara del av detta.

SOAF har nu instiftat ett pris för bästa examensarbete inom OR-området, se annons i tidningen. Vi hoppas detta kan väcka intresse för OR och för SOAF. Uppmuntra gärna berörda att lämna in bidrag!

Planer för 2011 börjar ta form. Huvudnumret blir att åter ordna en konferens i september, och vi hoppas kunna upprepa succén från 50-års-jubileet.

Det stora intresset och engagemanget för SOAF:s Järnvägsgrupp inspirerar till att starta fler intressegrupper. Preliminärt avser vi starta en intressegrupp för OR inom sjukvård. Hör av dig om du är intresserad att medverka eller har förslag på andra intressegrupper som SOAF bör dra igång!

Bästa hälsningar

Martin Joborn
Ordf SOAF

Indhold

Aktuellt om SOAF
september 2010

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By Marcus Frantzèn and Amos Ng

A case study of applying simulation-based optimisation to a real-world scheduling problem

Operations research can be described as the application of scientific methods and techniques to decision-making problems. Scheduling is a typical problem addressed with operations research. Scheduling of a real-world flowshop production line maybe highly complex, in which sequence dependent setup times, constraints and long failures might affect the possibility to reach the production target. Scheduling can be described as the determination of the optimal sequence for operations on several machines. Despite more than half a century of research, theoretical flowshop scheduling problems remain largely unsolved.

Trying to find an optimal solution to a complex real-world scheduling problem is still very challenging in academia and industry alike.

Production planners in industry are very often faced with such kind of challenging scheduling tasks, when optimal schedules have to be determined to optimise the performance of the production line.

Not only the scheduling problem needs to be considered, but also the scheduling task and it's integration in the organization. This article describes the ongoing work of creating a real-time scheduling system to support, not only the work of production planners, but also the operators on the shop floor by re-generating feasible schedules when required.

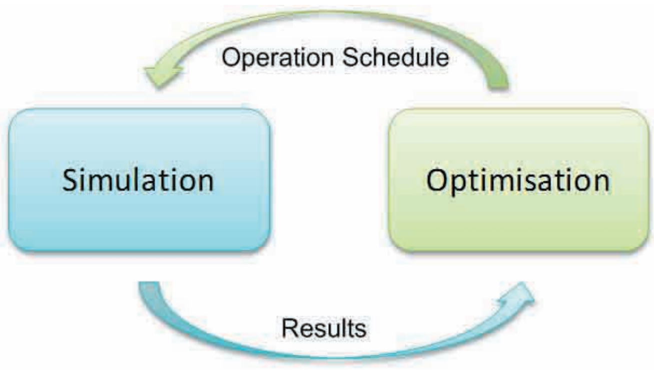

Figure 1. Simulation-based Optimisation

The real-world problem considered is a machining line in an automotive manufacturer in Sweden. The machining line is semi-automated with robots that feed machines inside the cells, but the loading, unloading and the decision of when or where to process different types of parts is decided by operators at each work area.

The consequence of these manual decisions in the machining line is that some machines might be locally optimized, but not the overall performance of the line. The scheduling problem may be categorized as a hybrid flow shop with several production stages, unrelated parallel machines, and multiple objectives:

$$F = w_1 f_{th} + w_2 f_{sh} + w_3 f_{tl} + w_4 f_{sa} + w_5 f_{st}$$

Where F is the overall fitness, as a

weighted function of f_{th}, line throughput (maximise); f_{sh}, shortage (minimise); f_{tl}, difference from target stock levels of various product types (minimise); f_{sa}, makespan (minimise) and; f_{st}, setup time (minimise).

Additionally, there are different constraints and properties: blocking, uncertainty, transportation times, missing operations (bypass), machine dependent setup times, sequence dependent setup times, lot splitting, to name but a few.

The scheduling problem deals with the simultaneous lot sizing and scheduling problem as the production is carried out with a make-to-stock policy. Because of the complexity of the problem, a discrete-event simulation (DES) model has been developed to model the existing production line.

In order to automatically search for optimal solutions, the determination of the optimal schedules can be solved by using simulation-based optimisation (SO) in which the developed DES is integrated with a genetic algorithm (GA). By integrating these two techniques, the performance of different schedules in a complex production system can be accurately evaluated by the DES model whilst the optimisation makes it possible to find an “optimal” schedule, provided that such a schedule can be found in a limited computational time.

The scheduling system

In the early stage of our investigation of applying SO to the scheduling problem, the top left part of Figure 2 was developed and tested.

The output of the solution was primarily a schedule that was printed and attached to each machine in the production line. The off-line tests showed that SO managed to generate better schedules when compared with the real-world production data.

However, when the generated schedules were implemented on the shopfloor, they were found to be impractical due to the manual handling of the paper distribution of the schedules. Therefore, in later stage of the development, the scheduling system was integrated with the shopfloor database to monitor the actual dispatching at the machines, which can be seen on right-hand side of Figure 2.

When the optimisation is finished, the new schedule is transferred to OPTIMISE Information System (OIS) where

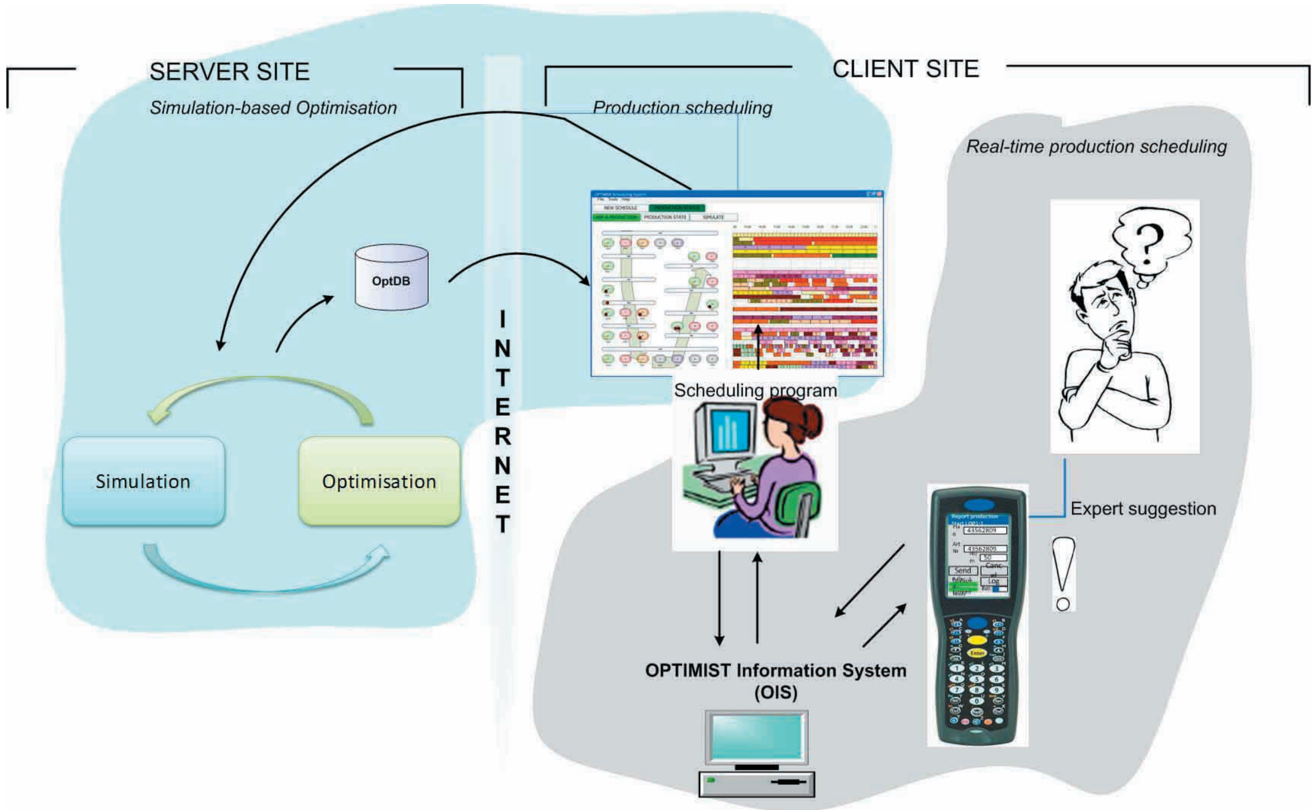

Figure 2. OPTIMISE Scheduling System

the current schedule is updated automatically. With such an extension, the scheduling system can then use real-time data from the production line and sends back expert suggestions directly to the operators through Personal Digital Assistants (PDAs).

The server site on left-hand side of Figure 2 handles the actual optimisation runs in OPTIMISE - a web-based parallel and distributed computing platform that supports multiple users to run experiments and optimisations with different simulation systems. The fully integrated system is therefore called OPTIMISE Scheduling System (OSS).

The simulation evaluations of the optimisation process are executed in parallel in order to obtain a good schedule in an acceptable period of time. The results from the optimisations are stored in the database called OptDB, and the user can view the results from the scheduling program. By displaying graphs, it provides the users with monitoring capability of the progress of the SO process.

For each solution generated (a schedule), it is also possible to study the different objective values. By selecting a solution the user can display the schedule in form of a Gantt chart, or in other words the predictive schedule independent from the scheduling approach used, i.e. sequences or dispatching rules. Other data are also possible to view, e.g. utilization, bottlenecks, stock levels over time, etc.

Graphical User Interfaces

There are two parts of the scheduling system that interact with the users: the scheduling program and the PDA-program. The PDAs (on left-hand side of figure 3) are mainly used by the operators to keep track of WIP, but are also used for transferring and displaying scheduling information.

When an operator asks for an expert suggestion in the PDA, a message will be sent to OIS in which a program will be started to determine the next job automatically using the current active scheduling approach, i.e. sequence or dispatching rule. Consequently, the expert suggestion is sent back to the PDA, based on both the scheduling approach used and the current available WIP.

The PDAs have linear bar code readers so that the process of scanning in WIP can be more efficient.

The scheduling user interface (on right-hand side of Figure 3) shows one of the tabs in the scheduling program.

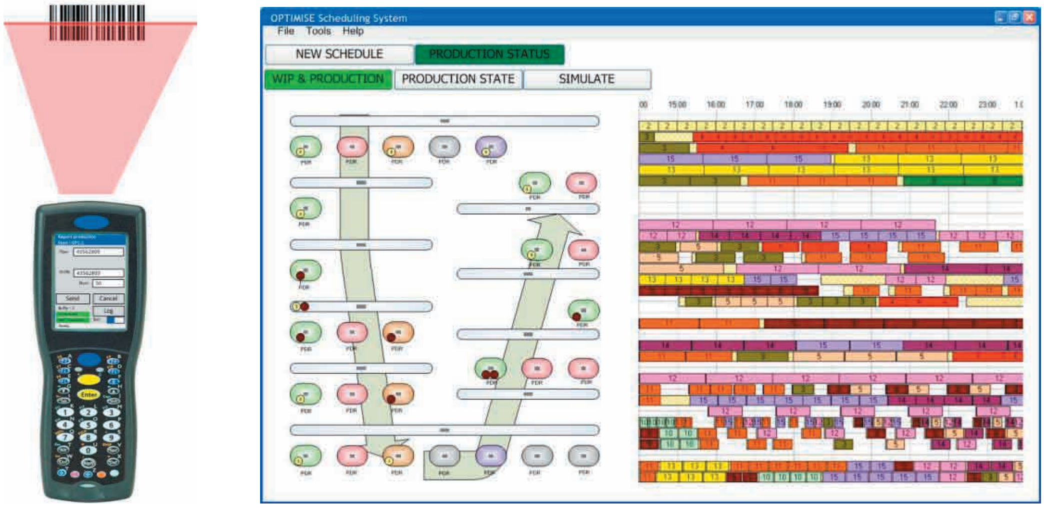

Figure 3. Personal Digital Assistants and the Scheduling Program

The scheduler may choose to create a new schedule (reschedule) or to monitor current schedule execution. When the optimisation is finished, the scheduler selects the best solution which is automatically transferred to OIS where the current schedule is updated.

It also lets the scheduler to start a simulation evaluation based on current status of the system, which gives the user a new predictive schedule.

Because of machine failures and other disturbances, the predictive schedule might not be good any longer. The evaluation will tell how the current schedule will perform if it continues with the same settings without making a rescheduling. Thereafter, the user is provided with the decision-making support to decide whether a rescheduling is necessary or not.

Conclusions

When a real-world scheduling problem is considered, it is often solved with substantial unrealistic simplifications, mostly without taking into account the scheduling task of the production planner.

If the scheduling problem is not studied together with the scheduling task of the production planner, important issues will be unidentified or remain unsolved. At the same time, the gap between theory and practice will probably remain if the real-world problem is not considered at an appropriate level of details.

Initial tests have shown that the scheduling application described in this paper can manage to generate better schedules when compared to the curent scheduling practice used in the production line. The work now underway is the full-scale test of OSS, both offline in a virtual environment and online in the real-world production.

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By Sin C. Ho

Manpower scheduling for airline catering

Introduction and problem description

The research presented in this article is motivated by airline in-flight catering operations. Most airline catering companies operate globally; the company that motivated our research caters to more than 270 airlines at 180 airports in 49 countries and produces around 369 million airline meals a year.

The supply chain for airline catering is complex. The number of meals needed for each flight is often not known until minutes before the flight takes off, while the meal preparation process has to be initiated days earlier. The most time-critical aspect is that the meals must be delivered and stowed on the aircraft on the tarmac during a very tight time window.

This project focuses on this last aspect of the operations. Airline meals for a flight are prepared in the kitchen (production) facilities at the airport and packed into trolleys that are specific to the particular aircraft type and layout configuration used for the flight. After the meals are placed in the trolleys, usually just a few hours before the scheduled departure time of the flight, the trolleys are placed in a holding area ready for transportation to the aircrafts. Trolleys from the previous flight of the aircraft (if it is a turnaround flight) also need to be unloaded from the aircraft before the necessary items are loaded on board.

To ensure microbial safety of meals, freshly prepared meal trays have to be kept at a certain temperature and cannot be left unrefrigerated for longer than a certain period. The vehicles used for transporting meals to and from the aircrafts are generally not refrigerated, thus, trolleys and carts cannot leave the production unit too early, otherwise the meals will get contaminated. Each vehicle is normally crewed by a delivery team consisting of one driver and one loader. The delivery team is responsible for loading/unloading the vehicle, driving to and from the aircraft, and unloading/loading the aircrafts.

Hong Kong International Airport is one of the world's busiest airports for passenger traffic, with about 85 international airlines providing flights to and from Hong Kong. On average, there are over 700 flights serving over 120 thousand passengers per day. These airlines employ different aircrafts of various sizes and configurations. The way the trolleys are loaded in the respective galley compartments differs from airline to airline, and from aircraft to aircraft. Each delivery team member has the skills to do the loading of aircrafts of a number of airlines, but usually cannot handle *all* the airline/aircraft configuration combinations.

A roster specifying the shift hours for each worker scheduled to be on duty is given for each day. Each worker has the status of either a driver or a loader. Each loader must be in a team with a driver, while a driver might be in a team with another driver or by himself. Vehicles leave the production unit for an aircraft to unload/load the aircraft before returning to the production unit.

The flight-loading operations that are the focus of this research is a manpower allocation problem with time windows and job-skill constraints. A daily flight plan is given with information on the estimated times of arrivals and departures of the flights, as well as the aircrafts and configurations used.

»...What makes this problem difficult is the combination of shift-hours restrictions and skills-compatibilities.«

Each flight is labeled as an *inbound flight*, a *turnaround flight* or as an *outbound flight*. An inbound flight is given a Standard Time of Arrival (STA) and stays overnight after it arrives. A turnaround flight is given both a STA and a Standard Time of Departure (STD), and it departs on the same day as the day of arrival. An outbound flight is a flight which has arrived the day before or even earlier, and is given a STD.

long, whereas the time-window for inbound flights (where only used trolleys have to be cleared) is usually longer.

The service of each aircraft must be realized by a team whose skills are compatible with the particular configuration of the aircraft, and must be completed within the flight's time window and the team's shift hours. The overall objective is to maximize the number of assigned flights and to create a balanced schedule.

What makes this problem difficult is the combination of shift-hours restrictions and skills-compatibilities. In our problem, not every worker is able to load every aircraft due to skills incompatibilities, and shift-hours may clash with the flight schedule. In addition, the requirement of team composition

Each flight is associated with a service duration which specifies the time needed to unload/load the delivery vehicle, the travel time to and from the aircraft, and the time needed to unload/load the aircraft. There is also a time window for each flight during which service must be performed. The time window for turnaround flights is usually very short (less than one hour). Outbound flights also have tight time windows since food cannot be left on an unpowered aircraft for too

– that is, how the drivers and loaders are combined to form teams – is vital to whether or not feasible solutions exist. In our model, once the teams are formed, they stay fixed for the rest of the shift. Making the workers move from one team to another does not comply with the current practice of most airline caterers. Thus, we opted for having teams fixed.

For the remainder of this article, we will refer to a flight as a

job. The overall manpower-scheduling problem consists of constructing a set of teams, teams-to-jobs assignments and job start-times such that a balanced schedule which maximizes the number of assigned jobs is made.

A solution to the manpower scheduling problem is a plan consisting of the team formations, where each team is assigned some jobs. A feasible solution is defined as a complete solution where all jobs are assigned and all jobs satisfy the following requirements:

• The job must start and be completed within its time window.

• Each job is assigned to no more than one team. (This constraint is relaxed later on.)

• The job must only be assigned to a team with the required skill.

• A team can only be assigned a job if it can be completed within the team's shift.

• A team can only work on one job at a time.

The primary objective is to maximize the number of assigned jobs. Sometimes it may not be possible to assign all jobs in a feasible manner. Thus, a schedule with the minimum of skills and/or shift-hour violations is preferred.

»...A good solution needs to be feasible and balanced. A balanced schedule is characterized by even distribution of jobs among the teams.«

The airline caterer is also interested in having a good solution. A good solution needs to be feasible and balanced. A balanced schedule is characterized by even distribution of jobs among the teams. Sometimes a balanced schedule may be hard to achieve due to the number of jobs, the number of teams, skills match and time restrictions.

So far we have described the basic manpower scheduling problem. The catering company that motivated this study is very interested in the efficacy of two alternative modes of operation. These alternatives are variants of the basic manpower scheduling problem.

1. Trips containing two jobs

In the first variant of the problem, a team may do two jobs in one trip. Motivation for this comes from the fact that the production unit is located outside of the Hong Kong International Airport (it takes about 15 minutes to travel from the production unit to the tarmac). By doing two jobs before returning to the production unit, savings in service time are obtained (as travel time is reduced).

2. Job assigned to two teams

In the second variant of the problem, we consider the possibility of assigning two teams to do a job. The workload of the job is shared equally by the two teams. Hence, the time that each team spends on servicing the job is reduced compared to not sharing the job.

Solution method

We have developed a two-stage solution approach for solving the basic manpower scheduling problem and its two variants. In the first stage, we solve a pairing problem where two workers are grouped together to form a team. Jobs are then assigned to teams in the second stage. For both of the stages, heuristics are developed to solve the problem under study.

For the first stage, we proposed a greedy heuristic to match workers from the same shift to form teams. The criterion for selecting pair of workers is based on the size of the union of the two workers' skill-set. The aim of this heuristic is to find a pairing of the drivers and loaders so that the sum of the sizes of skill-sets of the teams is maximized.

For the second stage, we implemented a tabu search approach for assigning jobs to teams for creating a schedule. The neighborhood structure used is the insertion move, where it is adapted to conform with different variants of the problem. In order to explore a wider part of the solution space, frequently made moves are penalized. As feasibility may be difficult to achieve, search in infeasible regions of the solution space is also allowed to be conducted.

The heuristics were coded in C++ and all experiments were carried out on a Pentium 4, 2.8 GHz computer. Computational experiments were conducted on a set of real-life instances (provided by the airline caterer) and on a set of generated test instances.

Experimental results show that the tabu search heuristic generates good solutions that satisfy the balance requirements using only 7-19 seconds of computing time (computing time depends on the problem variant). Experiments also show that the tabu search heuristic outperforms the simulated annealing heuristic that was implemented for comparison purposes. The results also indicate that the variant of allowing a job to be shared between two teams seems to be a better choice as a mode of operations.

For more details, see Ho and Leung (2010).

Concluding remarks

This research project is an example on how operations research can be used to solve real-live operation problems. Operations managers at the airline catering company spend 2-3 hours daily to form teams and assign jobs. They struggle in making feasible schedules. This project does not only help them in achieving their goal, it also assists in increasing the efficiency of the operations.

Reference

Ho, S. C. and Leung, J. M. Y., "Solving a manpower scheduling problem for airline catering using metaheuristics", *European Journal of Operational Research*, 202(3): 903-921, 2010.

Sin C. Ho, Assistant Professor affiliated with CORAL (Centre for OR Applications in Logistics), Department of Business Studies at Aarhus School of Business, Aarhus University.

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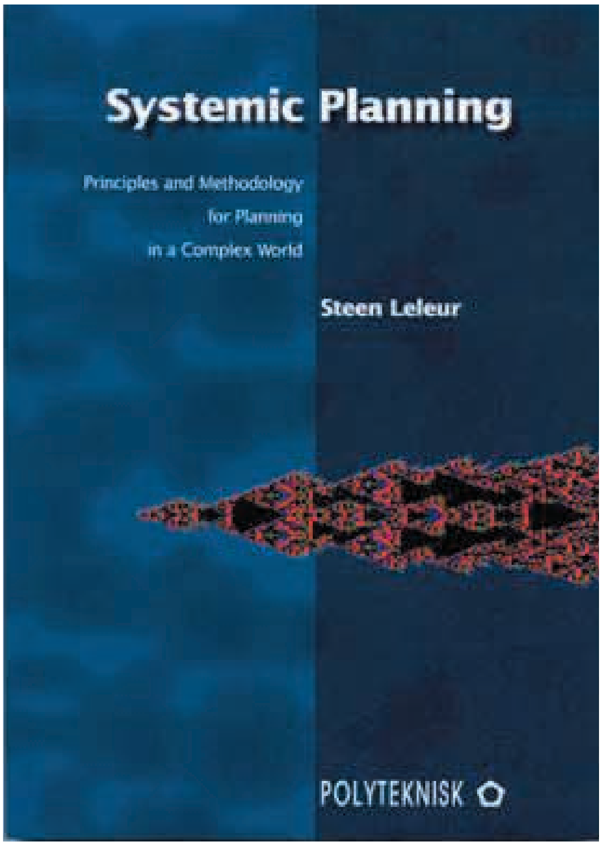
By Victor Vidal

Systemic Planning, Principles and Methodology for Planning in a Complex World, by Steen Leleur, Published by Polyteknisk, 2008, Second Edition, ISBN 978-87-502-1004-7

This book presents modern principles and methodology for planning in a complex world. It sets out systemic approach to planning, among other things, by applying "hard" and "soft" methodologies and methods in combination.



It treats this topic by taking a broad sweep from the rationales that can be found in the theoretical developments of the 20th century in systems science and the most recent complexity theories, to an outline of the qualifications and skills necessary for an envisioned systemic planner. Some relevant methodology is set out: a planning framework SCOPE and a multi-criteria method COSIMA.

As indicated in the title, the main concern of this book is with principles and methodology for planning in a complex world. Getting to grips with the notion of "systemic" is therefore important. The term systemic in a quite comprehensive way, i.e. as including both quantitative ("hard") and qualitative ("soft") issues relating to both concepts and methods. By referring to systemic planning, it wants to define a conception of planning that includes both its more conventional meaning - as a kind of special case - and new ideas that relate to issues of societal complexity which necessitate a renewal of thinking about planning.

We live in a complex world. Accordingly, this world is not always easily comprehended in a way that would allow our preparations for future-oriented action to be rational in accordance with some chosen standard. What then is the role of planning? How do we get support for future-oriented decision-making? These and other questions reside within a fundamental and more wide-ranging one: what becomes of the meaning of planning when unpredictability and complexity seem to characterise the planning task ahead of us? Possible and hopefully plausible answers to this question are set out in this book.

Dr. techn. Steen Leleur, is professor of decision support systems and planning at the Technical University of Denmark. On the basis of development in systems science and research in planning theory and technical modelling, he has developed a new framework for planning which takes explicit account of complexity and uncertainty. Such an approach to planning is highly needed in a wide range of today's application areas in society and business.

Contents

In Chapter 1, the foundations of systemic planning are laid out as we identify and seek to get to grips with three different types of complexity: detail complexity, dynamic complexity and what is called preference complexity. This leads to a clarification of some of the ideas that constitute systemic thinking and influence the development of systemic planning.

Chapter 2 examines what are presented as the three waves of systems science. By reviewing the work of the major systems researchers of the 20th century, we obtain insights that can assist in ramifying and enriching the foundations of systemic planning laid down in the first chapter. This makes it possible to formulate the contents of a systems-based research approach to planning.

In Chapter 3, a communication-based planning model is developed by making use of the theories set out by the German sociologist Jürgen Habermas. This model makes it possible to focus on a wider concept of rationality in the planning process and thereby reorient our attention with regard to the content of an appropriate planning practice.

The model makes it clear why traditional, so-called rational, comprehensive planning (or analytical planning) is insufficient - and sometimes even misleading - in complex settings, and what issues we need to focus on to reconsider it. On this basis we take a closer look at learning and causality, both of which thanks to specific theoretical developments, are found to contain insights that can prove helpful in renewing planning. Finally, an outline of a new systemic type of planning is presented.

The final Chapter 4 presents the contours of the hypercomplex society seen as the upfront challenge demanding a renewal of planning. A basic recognition is that societal types shift to make it possible to cope with ever increasing complexity. Applying the German sociologist Niklas Luhmann's theories, attention is given to the concepts of contingency and functionally differentiated societal systems. On this basis, the theme of planning, politics and power is actualised. Finally, the qualifications of the systemic planner are listed as a kind of summary of selected findings; together they serve as suggested guidance on systemic planning.

An Epilogue about systems science and complexity seeks to compare the current development trends in systems science by focusing on some main characteristics. It concludes that there is some potential in applying complexity theory, but adds the qualification: if not yet as a science then at least as a sort of wide-ranging awareness.

In two appendices some methodological exemplification is given. Specifically, this concerns SCOPE, which is a framework for planning in complex settings, and COSIMA, which is a kind of multi-criteria methodology that, because of its flexibility, is seen as useful in a multi-methodology approach. Finally, the last appendix presents some views about the future development of systems science and complexity.

Final Remarks

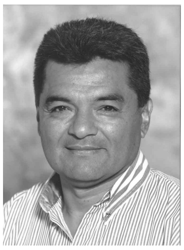
I highly recommend this book to PhD and graduate students in engineering, business and other fields. It will also be useful to all professionals, across a wide range of employment areas, who share an interest in renewing planning practice. Such an endeavour is seen as both important and timely, recognising that many complex planning tasks necessitate organisations – be they public or private – to engage in planning to prepare proactive decision-making.

An easy to read and use version of this book has been published in Danish language, see [1].

With the purpose of providing further information on systemic planning, a website has been established with relevant download material, links, etc.: www.systemicplanning.dk.

References

1. Leleur, Steen (2008) At Navigere Mod Fremtiden – systemisk planlægning som ide og metode, Polyteknisk Forlag, Lyngby, Denmark.



Prof.em. René Valqui Victor Vidal. Kunstner, digter, mm.

Victors vigtigste forskningsområde er problemstrukturering og løsning indenfor matematisk modellering, samfundsvidenskab og billedkunst.

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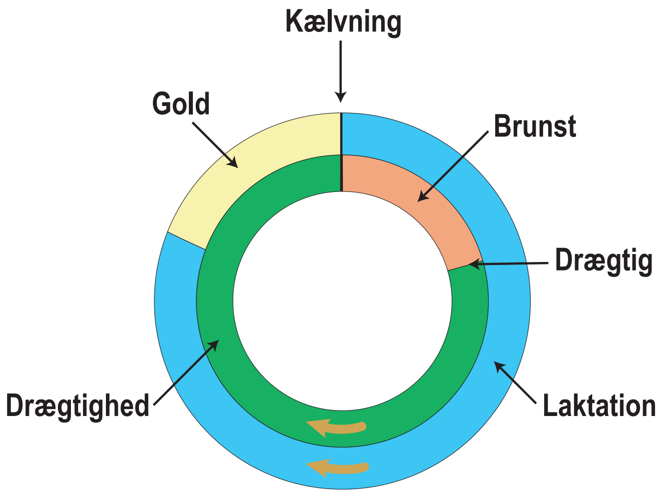
Denne artikel var i sidste nummer af ORbit opsat forkert. Derfor genoptrykkes den her. Redaktionen beklager.

Af Lars Relund Nielsen og Erik Jørgensen

Det optimale udskiftningstidspunkt for en malkeko

Med større besætninger i landbruget stiger behovet for værktøjer, der automatisk overvåger og beregner nøgletal for den enkelte malkeko. Et vigtigt nøgletal er koens økonomiske værdi. Når dette tal kan beregnes løbende for hver ko, er det muligt at rangere køer i besætningen ud fra de allermest aktuelle oplysninger samt bestemme det optimale udskiftningstidspunkt.



Figur 1. Laktationscykelen for malkekoen.

Problemstilling

En malkeko begynder at yde mælk efter kælvning af sin første kalv. Efterfølgende kan koens liv betragtes som en række af laktationer (perioden mellem 2 kælvninger). Dette er illustreret i Figur 1, hvor den yderste cirkel omhandler økonomien gennem perioden. Det blå område er perioden, hvor koen giver mælk og hermed et økonomisk afkast. Herefter forberedes koen til næste kælvning (gult område). Den inderste cirkel beskriver koens reproduktionscykel. Nogle uger efter kælvning kommer koen i brunst og det gælder nu om at inseminere koen på det rette tidspunkt indenfor 1-2 døgn (orange område). Hvis inseminationen lykkes indtræder koen i drægtighedsperioden (grønt område), som varer ca. 282 dage.

Set fra et økonomisk synspunkt er der en række problemer, man kan betragte. Da koens ydelse topper relativt hurtig efter kælvning (jvf. Figur 2), gælder det generelt om at gøre koen drægtig så hurtig som muligt. Derfor er det meget vigtigt at kunne bestemme det optimale tidspunkt for insemination (en periode på ca. 12 timer). Hvis en brunst overses og det ikke lykkes at gøre koen drægtig, skal man vente ca. 21 dage til næste brunst. Hvis det ikke lykkes at gøre koen drægtig, må den udskiftes.

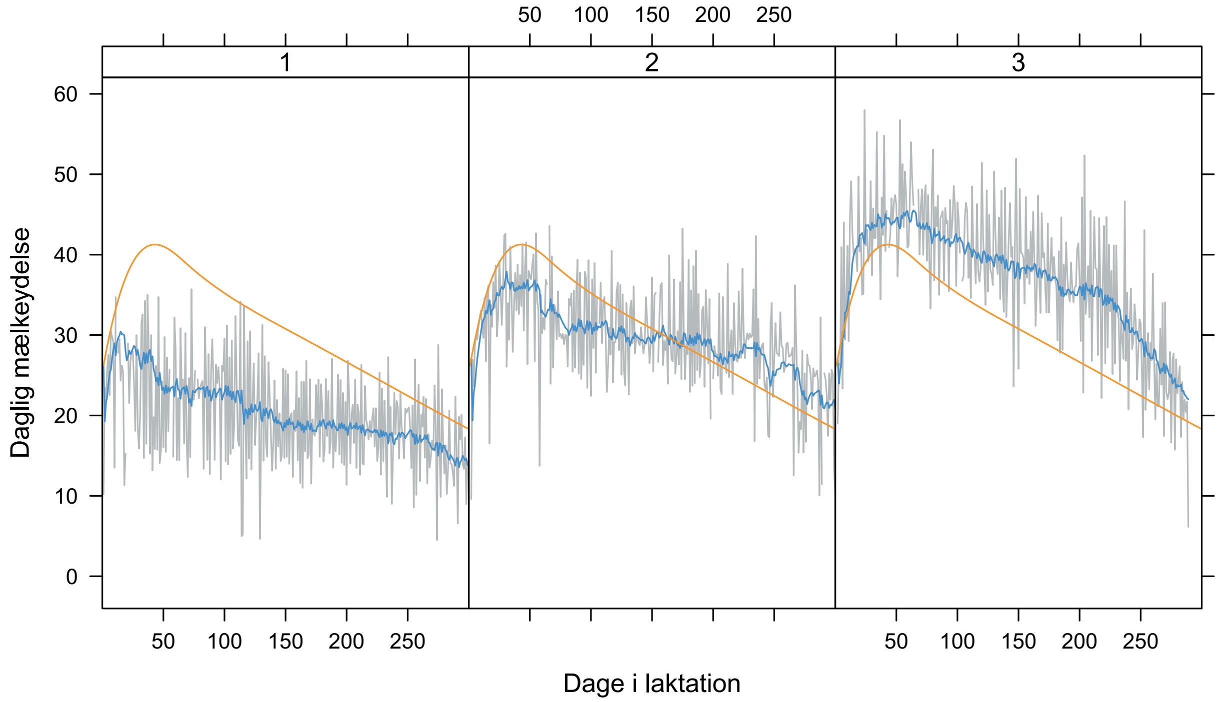
Ydelsen kan variere meget, når man betragter forskellige køer. Dette kan ses i Figur 2, hvor den daglige ydelse (grå linje) for 3 køer er vist. Desuden falder ydelsen med alderen af koen. Hvis man betragter en besætning er spørgsmålet nu, hvilken ko skal udskiftes, i hvilken laktation og hvornår i laktationen skal det gøres?

Ved hjælp af forskellige sensorer og matematiske modeller er det muligt at give et mere præcist svar på disse problemer. For eksempel kan automatiske målinger af mælkeydelsen bruges til at beregne det optimale udskiftningstidspunkt, og automatiske målinger af hormonet progesteron i mælken bruges til at forudsige brunst og dermed det optimale inseminationstidspunkt.

I denne artikel betragtes modeller, der baseret på den daglige ydelse, beregner og estimerer koens økonomiske værdi dagligt samt det optimale udskiftningstidspunkt.

Model til at forudsige ydelsen

For at kunne sammenligne køer i besætningen er det vigtigt at vide hvad besætningen som helhed yder. Derfor beregnes først laktationsydelseskurver for en gennemsnitsko ud fra ydelsesdata fra selve besætningen (orange



Figur 2. Ydelsen for 3 køer i tredje laktation. Kurverne er: Den gennemsnitlige ydelseskurve for hele besætningen (orange), daglig ydelse for den enkelte ko (grå) og gæt på koens ydelse i morgen (blå).

linje i Figur 2). For en specifik ko er det nu muligt dagligt at vurdere dens ydelse i forhold til gennemsnittet. Dette er illustreret i Figur 2 hvor vi betragter 3 køer i besætningen. Den første ko i figuren yder under gennemsnittet, den anden yder omkring gennemsnittet og den tredje over gennemsnittet.

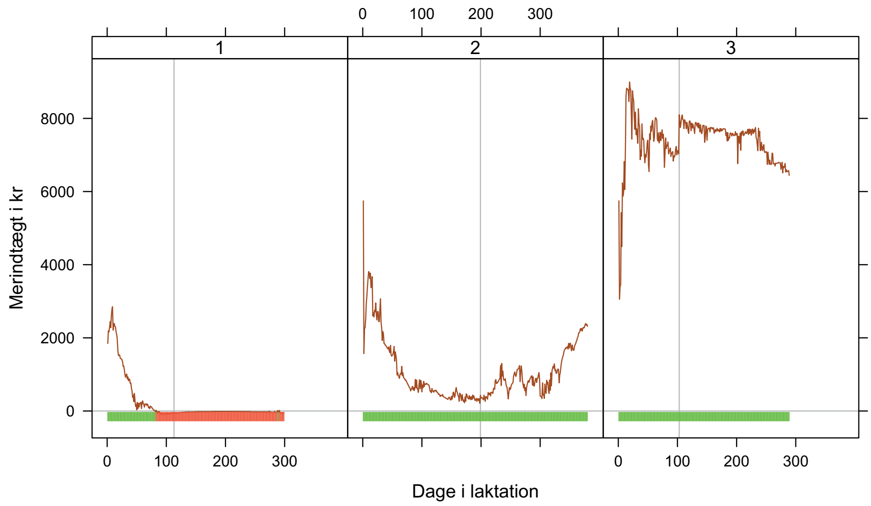
Samtidig formuleres en state space model der kan bruges til at beregne koens produktionspotentiale i forhold til gennemsnittet. Hvis produktionspotentialet er større end nul betyder det at koen yder mere end en gennemsnitsko. Tilsvarende hvis produktionspotentialet er mindre end nul yder koen mindre end gennemsnittet. Desuden kan modellen bruges til at forudsige koens fremtidige ydelse (blå linje i Figur 2).

Model til at beregning af økonomiske værdi og udskiftningstidspunkt

Til at bestemme koens forventede økonomiske værdi bruges en Markov beslutningsproces, dvs. en stokastisk proces, der indeholder sandsynligheder for koens fremtidige tilstande. Modellen har daglige trin svarende til hver dag i laktationen. Hvert trin opdeles i en række tilstande, der beskriver koens produktionspotentiale og drægtighedsstatus. State space modellen beskrevet i ovenstående afsnit indlejres i modellen og bruges til at bestemme overgangssandsynlighederne til næste trin i processen. Det totale antal tilstande i processen er 3.011.884.

Ved brug af stokastisk dynamisk programmering kan man beregne den optimale beslutning (behold koen eller udskift den) givet koens tilstand og dagen i laktationen. For en specifik ko er det nu muligt for hver dag i laktationen at bestemme koens produktionspotentiale ved brug af state space modellen. Dette gøres ud fra de ydelsesmålinger, vi har registret gennem laktationen. Givet produktionspotentiale og drægtighedsstatus kan vi identificere, hvilken tilstand koen er i, og herved se hvilken beslutning, der er optimal samt bestemme koens økonomiske værdi. Denne værdi er merindtægten ved at beholde koen til det optimale udskiftningstidspunkt, frem for at udskifte den nu.

Metoden er illustreret i Figur 3 for de samme køer som viste i Figur 2. Bemærk at ko nummer 1 anbefales udskiftet allerede 80 dage henne i laktationen, mens hverken ko nummer 2 eller 3 anbefales udskiftet gennem den tredje laktation. Yderligere ses det, at ved højt ydende køer sker der en stigning i den forventede merindtægt når koen konstateres drægtig. Dette skyldes at vi nu med stor sandsynlighed ved, at vi kan beholde koen en laktation mere.



Figur 3. Merindtægten ved at beholde koen til det optimale udskiftningstidspunkt frem for at udskifte den nu. Den lodrette linje indikerer positiv drægtighedstest. Den vandrette blok nederst i figuren viser om koen skal udskiftes (rød) eller beholdes (grøn).

Yderligere læsning

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Fakta

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Studerende fra DTU Management vinder GRØN DYST

I løbet af tre uger i juni arbejdede mange studerende arbejdet hårdt med deres projekt til GRØN DYST.

GRØN DYST var et nyt uddannelsesinitiativ på DTU. Med GRØN DYST sættede DTU fokus på bæredygtighed, klimateknologi og miljø i alle DTU´s uddannelser. Målet var at indlejre det grønne aspekt i de eksisterende kurser på DTU. På GRØN DYST præsenterede de studerende deres projekter og dystede om at vinde priser.

Kulminationen på arbejdet var en studenterkonference, hvor de studerende præsenterede deres projekter og resultater for undervisere og studerende samt dommerpaneler med repræsentanter fra det politiske liv, erhvervslivet og universitetsverdenen. I alt 90 projekter var tilmeldt GRØN DYST.

Der kunne dystes inden for fire kategorier, og **Kasper Bislev Katterup** fra DTU Management vandt kategorien “bedste projekt på kandidatniveau” med lektor Jesper Larsen som vejleder.

Projektet ”Optimization of Trailer Transport” angriber problemet med CO2-udslippet fra lastbilers godstransporter. 20 procent af CO2-udslippet i EU forårsages af gods- og transportsektoren. 40 procent af udslippet kommer fra transport af tomme lastbiltrailere.

I projektet blev der udarbejdet og beskrevet et optimeringsprogram, der kunne gøre det muligt at planlægge godstransport bedre, så tomme kørsler minimeres. Dette muliggøres ved at samarbejde og bytte trailere midtvejs. Dermed kunne man reducere antallet af tomme vogntog, som står for 25-40% af alle landevejstransporter og således nedsætte mængden af CO2 emission. Problemet var inspireret af et projektoplæg fra Transvision.

Med prisen fulgte en check på 25.000 kr. Priserne blev overrakt den glade vinder af klimaminister Lykke Friis og dekan Martin Vigild. Tillykke, Kasper! [njr]

Svenska Operationsanalysföreningen (SOAF)

OA-föreningens Exjobbspris i Operationsanalys 2010

SOAF har instiftat ett årligt *exjobbspris i OA* (Operationsanalys), för att uppmuntra just OA-exjobb. (För en definition av OA, se föreningens hemsida http://www.soaf.se/ under rubriken "Vad är OA?")

Vi tänkte oss främst att premiera exjobb av samma typ som artiklarna i tidskriften Interfaces (om ni är bekanta med den, se http://www.informs.org/Journal/Interfaces). Fast förstås inte på riktigt samma nivå.

Det betyder två krav:

1. *En lyckad tillämpning på ett praktiskt problem* (hos ett företag, myndighet e.d.).

Lyckad innebär att studien gjort nytta, d.v.s. att företaget (motsv.) fått ett beslutsunderlag av värde.

2. Att man *använt en vetenskapligt sund metod*, utan krav på att den ska vara metodmässigt revolutionerande.

Penganivån på priset är satt till 3000 kr per exjobb. Det viktiga anser vi vara erkännandet.

Vinnande exjobbare samt deras handledare får även diplom av SOAF.

Pristagarna förväntas vidare *presentera* sitt exjobb på ett SOAF-seminarium.

För att delta i tävlingen ska exjobbet vara godkänt under perioden från 1 november 2009 till 1 november 2010. Exjobbet skall sändas till undertecknad P O Lindberg i elektronisk form samt som en papperskopia. Det ska åtföljas av ett brev från handledaren eller examinatorn där det motiveras varför just detta exjobb ska få priset.

Deadline för insändande av exjobb för 2010 års pris är 15 november.

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ROADEF/EURO Challenge 2010

Ved årets store EURO konference i Lissabon i juli blev vinderne af den store Europæiske OR-konkurrence ROADEF/EURO Challenge kåret. Konkurrencen blev i 1999 startet af det franske OR-selskab ROADEF og har kørt hver andet år siden 1999. For 2010 blev der indledt et samarbejde med det Europæiske OR-selskab (EURO) omkring prisen i et forsøg på dels at støtte det franske initiativ dels at udbrede viden om konkurrencen yderligere.

Opgaven der skal løses skifter fra år til år. For 2010 prisen er udgangspunktet taget i en planlægningssituation fra EDF (Électricité de France). Konkurrencen er åben for enhver og har tre kategorier: junior teams, senior teams og parallel implementering.

Fra Danmark deltog der to hold; et junior hold fra Syddansk Universitet i Odense og et senior hold fra Danmarks Tekniske Universitet.

Det to danske deltagere præsenterer deres arbejde i forbindelse med ROADEF/EURO Challenge 2010 konkurrencen i dette nummer af ORbit: **Niels Kjeldsen, Rune Larsen, Steffen Elberg Godskesen og Thomas Sejr Jensen** (side 18 – 21) og **Richard Martin Lusby, Laurent Flindt Muller og Bjørn Petersen** (side 22 – 25).

Udfordringen

EDF kraftværker i Frankrig har en samlet kapacitet på 98.8 GW. Denne kapacitet dækker over en bred vifte af forskellige energikilder atomkraft, kul, olie og gas, vandkraft og andre vedvarende energiformer. Langt den største del af den producerede elektricitet stammer dog fra EDF's termiske kraftværker (90% i 2008), heraf står atomkraft for 86%. Denne konkurrence fokuserede netop på de termiske kraftværker som med mellemrum skal lukkes ned med henblik på vedligeholdelse og reparation og f.eks. for atomkraftværker udskiftning af brændselselementer.

Opgaven går ud på at planlægge driftsstopene på værkerne under hensyntagen til en række begrænsninger omkring sikkerhed, vedligehold, logistik og værkernes øvrige operationer samtidig med man tilstræber en produktionsplan med minimal omkostning.

Resultatet

De deltagende hold blev bedømt udfra en gennemsnitlig normaliseret score på de datasæt der blev stillet til rådighed af arrangørerne. Hvis et hold ikke kunne finde en lovlig løsning til et datasæt blev der for det datasæt brug den dobbelte værdi af den dårligst indsendte lovlige løsning som værdi. Gennemsnittet blev udregnet over 10 af de sværeste datasæt der var til rådighed.

Det bedste junior hold kom ind på en 2. plads i den samlede stilling. Værd at bemærke er også at inden multithread optimeringsmetode kunne slå den single threaded. Følgelig blev parallel implementeringen aflyst og istedet gav man en "special pris" til det hold der fik flest bedste løsninger.

Samlet resultat

Oversigten over samlet resultat kan findes på http://challenge.roadef.org/2010/result.en.htm. Her præsenterer vi de 3 beste hold inden for hver katetori:

Senior hold

- Vinder: S21 David Savourey, Vincent Jost, Christoph Dürr, Nora Touati, Antoine Jeanjean, Polytechnique et Bouygues e-lab, France (4000€ præmie)

- Nr. 2: J08 Roman Steiner, Sandro Pirkwieser, Matthias Prandtstetter, Vienna University of Technology, Austria

- Nr. 3: S14 Julien Darlay, Louis Esperet, Yann Kieffer, Guyslain Naves, Valentin Weber, Laboratoire G-SCOP, France and McGill University, Canada

Junior hold

- Vinder: J08 Roman Steiner, Sandro Pirkwieser, Matthias Prandtstetter, Vienna University of Technology, Austria (2500€ præmie)

- Nr. 2: J06 Steffen Elberg Godskesen, Thomas Sejr Jensen, Niels Kjeldsen, Rune Larsen, Dept. of Mathematics and Computer Science, Univ. of Southern Denmark and DONG Energy A/S, Denmark (1000€ præmie)

- Nr. 3: J05 Lauri Ahlroth, Henri Tokola, Andre Schumacher, Aalto Univ., School of Science and Technology, Finland (500€ præmie)

Prix spécial du jury

- S24 Johan Peekstok, Eelco Kuipers, BeImproved, Nederlands (6 bedste løsninger, 2000€ præmie). [jla]

Vinderen af 2. præmie i ROADEF/EURO konkurrencen 2010 blandt junior hold

Af Niels Kjeldsen, Rune Larsen, Steffen Elberg Godskesen og Thomas Sejr Jensen

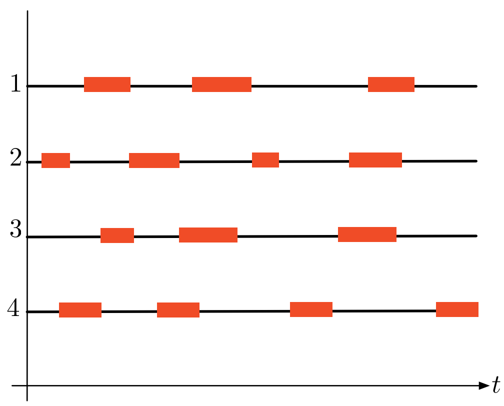
ROADEF/EURO Challenge 2010 – Skedulering af atomkraft i energisektoren

Med jævne mellemrum arrangerer det franske selskab for operationsanalyse (ROADEF) og det europæiske selskab for operationsanalyse (EURO) en konkurrence hvor et optimeringsproblem fra den virkelige verden stilles som udfordring til forskere og virksomheder inden for optimering. Optimeringsproblemet formaliseres af ROADEF i samarbejde med en virksomhed der også leverer de datasæt der regnes på. For at deltage i konkurrencen skal man indsende et program der løser problemer af den stillede type. De indsendte programmer evalueres på en række kendte og en række ukendte datasæt. Det hold der i gennemsnit klarer sig bedst, vinder konkurrencen.

1. Et komplekst skeduleringsproblem fra industrien

I konkurrencen for 2009/2010 var problemet fra det franske energiselskab Èlectricité de France (EDF) og bestod i at planlægge vedligeholdelse af og produktionsniveauer for atomkraftværker i Frankrig.

I forbindelse med vedligeholdelsen stoppes kraftværket og det nukleare brændsel genopfyldes. Produktionsniveauerne skal vælges så efterspørgselen på elektricitet altid er dækket. Efterspørgslen varierer over tid og kendes på planlægningstidspunktet ikke med sikkerhed. Hvis der til et givet tidspunkt er for lidt kapacitet på atomkraftværkerne, kan alternative, men dyrere, kul- og gaskraftværker bruges til at dække den resterende efterspørgsel. Beslutninger om vedligeholdelsestidspunkter og produktionsniveauer skal tages så produktionsomkostningerne minimeres. Dette svarer i store træk til at maksimere mængden af elektricitet der produceres af atomkraftværkerne, men også til at placere denne produktion når omkostningerne på de alternative kraftværker er højest.



Figur 1. Eksempel på skedulering af vedligeholdelsesperioder for fire kraftværker. De røde kasser repræsenterer vedligeholdelsesperioder.

EDF har stillet udfordringen da de ikke er fuldstændig tilfredse med deres nuværende håndtering af problemet og derfor gerne vil have inspiration og finde potentielle samarbejdspartnere. Problemet er, i vores optik, svært af flere årsager. For det første er problemet NP hårdt, og instanserne er af en væsentlig størrelse. For det andet er problemet kompliceret fordi der er mange tekniske betingelser til vedligeholdelsesperioderne og produktionsniveauerne. Disse betingelser går det svært at finde en lovlig skedulering af vedligeholdelsesperioder som også muliggør en lovlig løsning til produktionsplanlægningsdelen.

Kravene til skeduleringen kommer fra sikkerhedsmæssige og resourcemæssige begrænsninger. Typiske eksempler på betingelser er at to vedligeholdelses-

perioder skal ligge mindst et antal uger fra hinanden, og at der maksimalt kan være et givet antal kraftværker til vedligeholdelse samtidig.

I Figur 1 ses et lille eksempel på skedulering af vedligeholdelse på fire kraftværker. De røde markeringer er vedligeholdelsesperioder hvor der ikke kan produceres elektricitet; uden for disse kan kraftværket producere.

Der skal typisk skeduleres omkring fem vedligeholdelsesperioder for hvert af cirka 70 atomkraftværker over en tidshorisont på fem år. Tidshorisonten er inddelt i op til 6.000 tidsskridt og i hvert tidsskridt skal op til 120 scenarier for efterspørgsel på elektricitet og priser på brændsel håndteres.

»...For det første er problemet NP hårdt, og instanserne er af en væsentlig størrelse. For det andet er problemet kompliceret fordi der er mange tekniske betingelser til vedligeholdelsesperioderne og produktionsniveauerne.«

Vedligeholdelsesperioder skal skeduleres så de begynder i starten af en uge. Dette giver omkring 250 mulige starttidspunkter for vedligeholdelsesperioderne. Skeduleringen af vedligeholdelse er fælles på tværs af scenarier og binder dermed alle scenarier sammen, hvorimod beslutninger om produktionsniveauer kan tages med hensyn til varierende efterspørgsel og omkostninger i de enkelte scenarier. For en mere detaljeret beskrivelse af problemet henvises til det officielle dokument på konkurrencens hjemmeside (http://challenge.roadef.org/2010/index.en.htm).

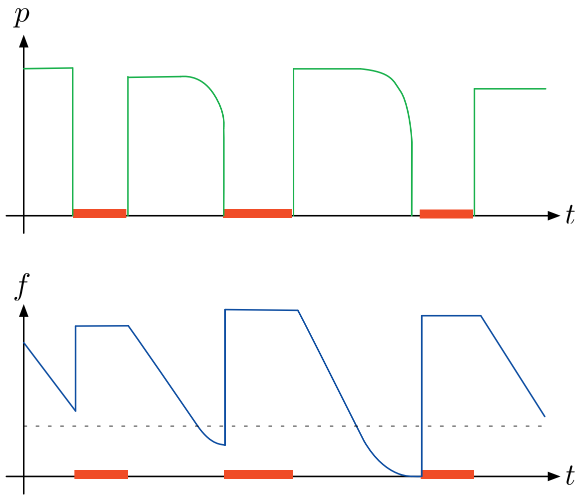
Her giver vi et kort overblik over vores arbejde med forskellige løsningsmetoder til det beskrevne optimeringsproblem. De fleste tekniske detaljer er udeladt, da der fokuseres på processen. Resultaterne blev præsenteret på EURO 2010 konferencen i Lissabon, og en videnskabelig artikel med uddybelse af algoritmerne er under udarbejdelse.

Vores løsningstilgang

Problemet kan formuleres som et lineært blandet heltalsproblem. Vores formulering gav dog for mange variable – blot de kontinuerte beslutningsvariable for produktionsniveauet for hvert kraftværk i hvert tidsskridt i hvert scenarie giver over 50 millioner variable (70 kraftværker x 6000 tidsskridt x 120 scenarier). Derudover er en linearisering af skeduleringsbetingelserne nødvendig, hvilket introducerer et stort antal binære beslutningsvariable i modellen. Tilsammen giver dette en lineær model som vi ikke anså det realistisk at løse.

Vi opgav derfor en komplet lineær model af problemet og fokuserede i stedet på andre løsningsmetoder som ikke nødvendigvis giver en optimal løsning. Som et første skridt i den retning har vi valgt at dekomponere problemet i en skeduleringsdel og en produktionsplanlægningsdel. Dermed bestemmes først placeringen af vedligeholdelsesperioder med meget lille hensynstagen til produktionsniveauer som først fastlægges i næste skridt.

Vores erfaring er at løsningmetoderne constraint programming og lokalsøgning ofte virker godt på skeduleringsproblemer. Vi arbejdede derfor videre med disse to tilgange parallelt, og det viste sig at være lettest at finde lovlige skeduleringsløsninger med en constraint programming model. Dette skyldes sandsynligvis at en løsning skal overholde mange skeduleringsbetingelser og at der derfor drages fordel af at constraint programming hurtigt detekterer at en delløsning er ulovlig.



Figur 2. Eksempel på produktionsniveau (øverst) og brændselsniveau (nederst) for det første kraftværk på Figur 1. Af figurerne fremgår det at brændselsniveauet falder når der produceres og når brændselsniveauet kommer under den stiplede linje, falder produktionskapaciteten gradvist.

For at få en komplet løsning fra den opnåede skeduleringsløsning skal vi vælge produktionsniveauer for alle kraftværker, tidskridt og scenarier. Til denne planlægning udviklede vi en grådig algoritme som har mulighed for at foretage backtracking i hvis resterende delproblem ikke har en lovlig løsning.

Øverst i Figur 2 ses hvordan produktionsniveauer for det første atomkraftværk fra eksemplet i Figur 1 er sat i et enkelt scenarie. Den grådige algoritme gennemløber tidsskridtene sekventielt og sætter kraftværket til at producere så meget elektricitet som det er i stand til, i hvert tidsskridt. Når brændselsniveauet kommer under et bestemt niveau, falder produktionskapaciteten gradvist. Når alt brændsel er brugt stoppes produktionen, og kraftværket kan først producere elektricitet efter genpåfyldning af nyt brændsel.

I forbindelse med hver vedligeholdelsesperiode skal det også besluttes hvor meget brændsel der fyldes på kraftværket. Hvis der fyldes for meget brændsel på kraftværket, risikerer man at have for meget brændsel ved begyndelsen af næste vedligeholdelsesperiode, hvilket gør løsningen ulovlig.

Hvis denne situation detekteres i forbindelse med produktionsplanlægningen udføres backtracking, dvs. planlægningen rulles tilbage til den tidligere vedligeholdelsesperiode, og mængden af brændsel der påfyldes, sænkes. Hvis der genopfyldes for lidt brændsel, risikerer man i stedet at producere meget lidt på atomkraftværkerne og dermed være nødsaget til at bruge de dyre alternative kraftværker.

Med den grådige produktionsplanlægning opnår vi de første lovlige løsninger til hele problemet, men de er af forholdvis lav kvalitet (dvs. høje omkostninger ved produktion af den efterspurgte mængde elektriciteten), da vedligeholdelsesperioderne i højere grad er placeret så løsningen er lovlig end så omkostningerne minimeres.

Derfor bruger vi lokalsøgning til at forbedre skeduleringen af vedligeholdelse. Lokalsøgningen laver små, tilfældige modifikationer til skeduleringsløsningen ved at rykke vedligeholdelsesperioder et par uger frem eller tilbage og så evaluere ændringen i den samlede omkostning ved at produktionsplanlægge de påvirkede kraftværker igen.

»...Vores erfaring er at løsningmetoderne constraint programming og lokalsøgning ofte virker godt på skeduleringsproblemer. Vi arbejdede derfor videre med disse to tilgange parallelt, og det viste sig at være lettest at finde lovlige skeduleringsløsninger med en constraint programming model.«

Ved at effektivisere algoritmen til produktionsplanlægningen er det muligt at lave en effektiv delta-evaluering. Hvis den nye løsning overholder alle skeduleringsbetingelser og mindsker den samlede omkostning, accepteres ændringen. Ved hurtigt at evaluere tilfældige ændringer og kun acceptere ændringer der mindsker den samlede omkostning opnår vi en løsning af meget bedre kvalitet.

Niels Hvidberg Kjeldsen modtager prisen ved EURO konferencen i Lissabon.

Resultatet af konkurrencen

Konkurrencen var åben for alle, men havde en junior kategori hvor deltagere ikke måtte have færdiggjort en ph.d.-uddannelse. Vi rangerede som nummer syv i den samlede konkurrence og som nummer to i juniorkategorien.

De samlede resultater findes på konkurrencens hjemmeside. Ud fra disse kan man se, at kun fire hold var i stand til at løse alle ti problemer. Af disse fire hold fandt ingen den bedst fundne løsning på nogen af datasættene, men pointgivningen var konstrueret således at tre af disse hold alligevel stod for top tre. Den endelige placering beror således i højere grad på den udvikledes metodes stabilitet end dens evne til at minimere den samlede omkostning.

Vores indsendte program fejlede på to af de ukendte datasæt, men vores lovlige løsninger er altid inden for top fire, og vores løsninger er typisk et par procent dårligere end den bedst kendte.

Således mener vi at vores metode har vist sig at være konkurrencedygtig, men manglede stabilitet for at blande sig helt i toppen af konkurrencen.

Efter konkurrencen er det med en mindre ændring lykkedes at løse de sidste af de ukendte instanser.

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By Richard Lusby, Laurent Flindt Muller and Bjørn Petersen

Bender's Decomposition Applied to the ROADEF/EURO Challenge 2010

Every two years since 1999 the French Operations Research Society, Recherche Opérationnelle et d'Aide à la Décision (ROADEF), has organized the so-called ROADEF challenge, an international operations research contest in which participants must solve an industrial optimization problem. Given the success of previous contests, this year it was jointly organized for the first time with the European Operational Research Society (EURO) and known as the ROADEF/EURO Challenge 2010. The competition was run in collaboration with Électricité de France (EDF), one of the largest utility companies in the world, and required contestants to solve a large scale energy management problem with varied constraints.

1. Introduction

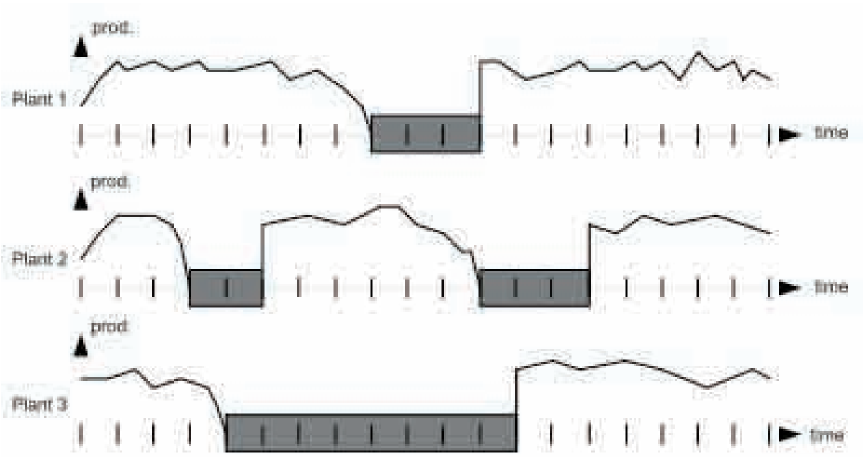
EDF's power generation facilities in France stand for a total of 98.8 GW of installed capacity, most of which is produced using thermal, and in particular nuclear, power plants. In 2008 thermal power plants accounted for 90% of its total electricity production of which 86% was delivered by nuclear power plants.

This year's challenge focused on the nuclear power plants, since these need to be regularly shut down for refueling and maintenance, and asked contestants to schedule these outages in such a way that the various constraints regarding safety, maintenance, logistics, and plant operation were satisfied, while minimizing the expected cost of meeting the power demand in a number of potential scenarios. The problem thus consisted of the following two dependent subproblems

1. Determine a schedule of nuclear power plant outages. This entails determining when the nuclear power plants should be taken offline and how much fuel should be reloaded at each. An outage lasts for some predefined (plant specific) period of time during which the nuclear power plant cannot be used for power generation. The coupling of an outage followed by a production period (until the next outage) for a nuclear power plant is termed a cycle and it is not uncommon to have to schedule up to six cycles for each nuclear power plant. In determining an outage schedule one must obey several safety requirements as well as observe restrictions arising from the limited resources available to perform the fuel reloading.

2. Given an outage schedule, determine a production plan for each of the online power plants, i.e. the quantity of electricity to produce in each time step, for each possible demand scenario. The power plants are divided into two categories termed Type 1 and Type 2, respectively. Type 2 power plants refer to the nuclear power plants and must be reloaded with fuel, while Type 1 power plants represents thermal power plants, which can be supplied with fuel continuously, such as coal, gas, and oil powered plants. Several technical constraints govern the possible levels of power production at each power plant. Due to the stochastic nature of power markets, one is required to consider multiple demand scenarios.

The concepts of cycles, outages, and production plans for three power plants are illustrated in Figure 1. The gray area



Fiture 1: Outages, Cycles, Production Plans.

indicates the time steps during which the plants are offline.

One important aspect of this years problem was its size: There were approximately one hundred power plants and scenarios, and the planning horizon was in the order of years, with a granularity down to hours. Which means that a solution alone can contain in the order of 10^8 variables.

2. Overview

Here we present a Bender's Decomposition based framework that we developed to solve the above problem and report on its performance for the set of test instances provided. We begin with a brief overview before explaining each step in more detail.

Bender's Decomposition is a well known decomposition technique for solving large scale stochastic optimization problems. This approach decomposes the original problem into a master problem and one or more independent subproblems.

For the ROADEF/EURO 2010 challenge we utilize the fact that as soon as a feasible outage/reloading schedule is obtained, the problem decomposes into n independent subproblems, where n is the number of possible scenarios in the instance under consideration. Thus, the role of the master problem is to find a good reloading/outage schedule and is modelled as a mixed integer program (MIP). The solution to this problem can then be used to identify production plans for each online power plant in each of the possible scenarios.

Each subproblem is modelled as a linear program (LP) and determines how much each power plant should produce in each time step so that the demand in each time step is satisfied. When constructing production plans one must observe several fuel stock level requirements at each of the nuclear power plants. In particular, one must respect the so-called AMAX and SMAX bounds. The former provides a bound on the maximum amount of fuel that can be on hand at a nuclear power plant when an outage occurs, while the latter specifies a bound on the maximum amount of fuel that can be on hand after a reloading has occured.

In addition to this one must respect several production level bounds at each power plant. Two such constraints, known as the power shut down curve (CT6) and the maximum modulation constraint (CT12), were two complicated to include in th LP formulation of the subproblem. The first states that once the fuel stock level at a given nuclear power plant falls below a certain threshold production must follow a piecewise linear decreasing function, while the second tries to ensure a high utilization of the nuclear power plants by stipulating that the average deviation of the production cannot be more than a certain tolerance from the maximum possible production level (however, only prior to the aforementioned threshold).

As a result, such constraints are not enforced when solving a given subproblem, but rather in a post-processing step that attempts to repair the relaxed subproblem solution.

In a typical Bender's Decomposition fashion, optimality cuts are constructed from the solutions to the subproblems and added to the master problem to direct it towards more promising reloading/outage schedules. In order, to avoid having to return feasibility cuts to the master problem, cuts are pre-emptively added to the master problem and these try to enforce SMAX/AMAX bounds.

These cuts also partly enforce CT6. When a solution, that potentially violates CT6 and CT12, is obtained, an attempt is made to repair it. First by shuffling production around within a cycle. If this is not possible, then fuel is moved between cycles. If it is still unrepairable, the refuel amounts are lowered. Finally, the solution is rejected if CT6 and CT12 cannot be satisfied.

When a feasible solution is obtained, a simple 2-opt neighborhood is explored to try to improve the solution quality (objective value). CPLEX 12.1 is used to solve both the master and subproblem.

3. Core Methodology

The algorithm is divided into the following three stages.

Stage 0

In Stage 0, the master problem is solved to integrality without the addition of any optimality cuts. The MIP model contains binary variables, which govern when the outage for each cycle of each nuclear power plant will occur (i.e. in which week of the time horizon), and continuous reload variables that indicate how much fuel is to be reloaded during each outage.

All constraints on incompatibilities between outage dates, such as the

Name	Total	Rem.
data0	36	28.78%
data1	3920	87.42%
data2	7941	88.39%
data3	8207	89.74%
data4	17514	89.37%
data5	15415	81.91%
data6	24683	85.58%
data7	35817	80.61%
data8	69481	67.15%
data9	69136	62.30%
data10	30061	85.43%

Table 1: Preprocessing results.

maximum offline capacity permitted, are included. Neglecting the optimality cuts is done in order to obtain a solution that is easy to repair so as to at least obtain a feasible solution to the problem.

The objective function of the master problem is to minimize the cost of refuelling and since no optimality cuts are initially included, any optional cycles will not be scheduled and thus we do not expect the quality of this solution to be very good. However, at least it is easy to find. The reason why we want to obtain at least one feasible solution is because of the rules of the competition, which gives a severe penalty to participants, who find no solution.

Prior to building the IP in Stage 0, extensive preprocessing is used to remove redundant binary variables from the model. Table 3 shows how crucial this preprocessing step phase is in reducing the size of the problem instance. The table gives the instance name, the total number of binary variables in the instance, and the percentage of these that are redundant.

Stage 1

In this stage of the algorithm, the root node of the relaxed master problem is solved, where the subproblems are solved to separate optimality cuts. We do not solve all subproblems per Bender's iteration since this would simply take too long (for large instances there can be as many as 120 scenarios).

A round robin approach is adopted in which only one subproblem is solved per Benders iteration. Since even solving a single instance of the subproblem can be time consuming, largely due to the fact that time step in the subproblem is much shorter (days or even as fine as hours), an aggregated version is used. In the aggregated subproblem, the time step is considered to be weeks and all demands are adjusted accordingly.

When no optimality cut has a magnitude of violation greater than some prespecified epsilon, or some predetermined time limit is reached, Stage 1 terminates.

Stage 2

In this final stage the master problem is solved to integrality without the addition of anymore optimality cuts. That is, a standard Branch-and-Bound algorithm is implemented from the root node and Cplex's "Populate" routine is used to collect integer solutions.

When an integral solution is found, all subproblems are solved to obtain a complete solution, each subproblem solution is repaired to ensure CT6 and CT12 are satisfied, and finally a 2-opt heuristic is run to improve the quality. The 2-opt procedure attempts to shuffle production between plants in an attempt to reduce production costs. The best found solution is retained and Stage 2 continues until either all integer solutions from the branch and bound tree are enumerated, or a prespecified time limit is reached.

Name	#Cuts	#Sols	#Rep	Dev	Avg
data0	5	1688	1688	0.0709%	
data1	6	140	129	0.0677%	
data2	39	32	32	0.3119%	
data3	14	35	35	0.2130%	
data4	23	14	14	0.4379%	
data5	20	11	11	0.1818%	0.2139 %
data6	20	9	9	7.3887%	
data7	5	10	6	66.4228%	
data8	1	4	3	3685.9110%	
data9	1	1	1	4779.6071%	
data10	320	2	2	93.7599%	1726.6179%

Table 2: Results for different problem instances.

4. Computational Results

The computational experiments were performed on a machine with 2 Intel(R) Xeon(R) CPU X5550 @ 2.67GHz (16 cores in total), with 24 GB of RAM, and running Ubuntu 10.4. The version of CPLEX used is 12.1. Table 2 gives statistics relating to our solution for each of the 10 data sets. It gives the following information: the number of optimality cuts added (#Cuts), the number of solutions found in stage 2(#Sols), the number of solutions found in stage 2 that were repairable (#Rep), the percentage deviation from the best known solution (#Dev), and the average deviation for the two test sets of five instances (#Avg).

As can be seen from the table, the solution approach performs satisfactorily on instanstances zero to five. These were the test instances used in the qualification phase of the contest and are less complicated than the second set of instances (data6 to data10). For the latter set, the algorithm runs into difficulty due to the large number of binary variables (particularly data8 and data9). As a consequence, the master takes longer to solve, less optimality cuts can be added, and ultimately fewer solutions can be evaluated.

Furthermore, formulating and solving the subproblem as an LP and repairing its solution so that it satisfies CT6 and CT12 appears to be an expensive process, despite the aggregation. This explains the poor performance on the second set of instances. The method, however, is an optimal approach and can provide a lower bound on the optimal solution to the problem. This could be used to benchmark the quality of solutions obtained using heuristics.

5. Conclusions

In conclusion, we have developed a Bender's Decomposition approach to solve the large scale energy management problem posed for the ROADEF/EURO 2010 challenge. On the second set of instances and 5 blind instances we placed 14th out of 19 teams in the final. One of the few optimal methods proposed, it was unable to compete with the heuristics given only 3600 seconds of computing time. The sophisticated approach can, however, provide information as to the quality of solutions through the lower bound information which can be obtained at each iteration of the Bender's algorithm.

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