A Survey on Robustness in Railway Planning

Planning problems in passenger railway range from long term strategic decision making to the detailed planning of operations. Operations research methods have played an increasing role in this planning process. However, recently more attention has been given to considerations of robustness in the quality of solutions to individual planning problems, and of operations in general. Robustness in general is the capacity for some system to absorb or resist changes. In the context of railway robustness it is often taken to be the capacity for operations to continue at some level when faced with a disruption such as delay or failure. This has resulted in more attention given to the inclusion of robustness measures and objectives in individual planning problems, and to the providing of tools to ensure operations continue under disrupted situations. In this paper we survey the literature on robustness in railway planning problems, considering how robustness is conceptualized and modelled for the individual problems of railway, the degree to which an overall railway robustness concept is present, and consider the future directions of robustness in railway planning.
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BFI (2017): BFI-level 1
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Scopus rating (2015): SJR 2.334 SNIP 2.412 CiteScore 3.59
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Scopus rating (2013): SJR 2.346 SNIP 2.735 CiteScore 3.25
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BFI (2010): BFI-level 1
Scopus rating (2010): SJR 2.477 SNIP 2.435
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 1
Scopus rating (2009): SJR 2.326 SNIP 2.577
Web of Science (2009): Indexed yes
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Web of Science (2001): Indexed yes
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A Branch-and-Price algorithm for railway rolling stock rescheduling

How to best reschedule their fleet of rolling stock units during a disruption is an optimization problem regularly faced by railway operators. Despite the problem’s high complexity, it is still usually solved manually. In this paper we propose a path based mathematical formulation and solve it using a Branch-and-Price algorithm. We demonstrate that, unlike flow based approaches, our formulation is more easily extended to handle certain families of constraints, such as train unit maintenance restrictions. The proposed algorithm is benchmarked on several real-life instances provided by the suburban railway operator in Copenhagen, DSB S-tog. When used in combination with a lower bound method taken from the literature we show that near-optimal solutions to this rescheduling problem can be found within a few seconds. Furthermore, we show that the proposed methodology can be used, with minor modification, on a tactical planning level, where it produces near-optimal rolling stock schedules in minutes of CPU time.

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Scopus rating (2009): SJR 2.39 SNIP 2.832
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Considering passenger and operator inconvenience in the scheduling of large railway projects

The continued development and renewal of railway infrastructure and technology is necessary to enable railway operators to provide high quality services subject to ever increasing demand. However, the execution of large infrastructure projects causes disturbances in the network due to the occupation of infrastructure over extended periods of time. In this paper we propose a multiobjective project scheduling optimization model for railway infrastructure projects that takes inconvenience caused to users of the infrastructure into account. We illustrate how the model can be used in an interactive way by planners based on their preferences, and we show that Pareto optimal solutions can be found in reasonable time using instances with realistic features. The result is a decision support model to aid infrastructure project planners in ensuring that passenger and operator inconvenience are also taken into account.

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Integrated Rolling Stock Planning for Suburban Passenger Railways

One of the core issues for operators of passenger railways is providing sufficient number of seats for passengers while keeping operating costs at a minimum. The process a railway operator undertakes in order to achieve this is called rolling stock planning. Rolling stock planning deals with deciding how to utilise the fleet of available train units in space and time. In this thesis, rolling stock planning has been studied, using as case study DSB S-tog, the suburban passenger railway operator of the City of Copenhagen. At DSB S-tog, the rolling stock planning process is subdivided according to time horizon into two subprocesses. Firstly, there is the long-term circulation planning process, in which planning is conducted for anonymous, virtual train units months in advance. Secondly, there is the short-term train unit dispatching process, which covers the execution of the long term circulation plan. In the train unit dispatching process, the anonymous, virtual train units from the circulation planning process will have real, physical train units assigned to them. The train unit dispatching process has a short-term time horizon of days, hours and minutes and makes sure the actual, real-world train services are performed. Disruptions are also handled in this process. In the long term circulation planning phase of rolling stock planning, a large number of railway-specific requirements must be taken into account: The physical railway infrastructure must be adhered to, e.g., platform and depot track capacities, the rules of the train control system and the order in which train units may be parked so as not to obstruct each other’s movements; All trains services of the timetable must have at least one train unit assigned; Only the available rolling stock can be used in the plan; The plan should provide seating capacity according to the passenger demand and provide an even distribution of flexible space for bicycles etc.; Planned shunting operations in the depot should have suicient personnel on duty; Train units must undergo interior and exterior cleaning, surface foil application and winter preparedness treatment at regular time intervals; At regular service distance intervals, train units must undergo scheduled maintenance etc., and consumables must be refilled; Certain train services must have train units with additional train control system equipment installed, special passenger counting equipment installed and/or perform predefined exposure of commercials.

In the short-term train unit dispatching phase of rolling stock planning, additional railwayspecific requirements include: Exterior graffiti removal and unscheduled maintenance on demand and sometimes within a given time frame; Make available train units to meet surveillance video recording requests from the police within a given time frame. Due to the large number of railway-specific requirements and their nature, rolling stock planning is traditionally conducted in a step-
by-step manner, in which the individual planning processes are not integrated with each other. Needless to say, this yields rolling stock plans that are either suboptimal or infeasible with regard to the requirements. In this thesis it is shown that it is possible to design and implement a rolling stock planning model integrating into one planning process all the railway-specific requirements of DSB S-tog, all at the same time. This integrated rolling stock planning model is implemented using a greedy heuristic and makes use of the novel (train) unit order conservation principle, implemented as special side constraints to a resource constrained shortest path algorithm. The integrated rolling stock planning model is tested extensively on 15 real-world, manually constructed rolling stock plan data instances. When run on these instances, the greedy heuristic can achieve an average economic gain of approx. 2% with processing times in all cases less than 1 hour 20 minutes. In addition to this, the greedy heuristic can make typically infeasible rolling stock plans feasible within just a few minutes of processing time. Moreover, in this thesis a number of different economic net value upper bound calculation models are designed, implemented and tested. The net value upper bound calculation models implement the railway-specific requirements to a varying degree and consequently expose different properties with regard to tightness of bounds and processing times. The net value upper bound model having the highest degree of requirements integration adheres to 47% of the requirements by count. Using this tightest net value upper bound calculation model, it is shown that the greedy heuristic mentioned before is able to gain approx. 1/3 of the relative gap between the net value of the original, manual plans and the net value upper bound. Moreover, it is shown that in most cases, the net value of the original, manual plans already lie close to the upper bound.

Furthermore, a branch-and-price based matheuristic integrated rolling stock planning model is designed, implemented and tested. It is shown that this type of matheuristic model is able to adhere fully to all railway-specific requirements, and that the vast majority of requirements can be integrated into the optimisation steps of the atheuristic algorithm. The branch-and-price matheuristic model can solve small instances (e.g., in the form of matheuristic iterations) to optimality. Used in conjunction with the greedy heuristic, the two methods combined can achieve an additional small gain in objective value not achievable using each method by itself. With a yearly cost of the rolling stock operation in the hundreds of million DKK, the potential benefit of a real-world application of the models to DSB S-tog is in the order of several million DKK per year. In addition to this, a substantial benefit can be gained by the way the models can automate the current, manual planning procedures. This will enable planners to invest more creativity and meticulousness into the planning process as a result of being liberated from manual planning procedures. For these reasons, DSB S-tog is eager to proceed with the real-world application of the models developed in this thesis.

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**Tramp ship routing and scheduling with voyage separation requirements**

In this paper we explore tramp ship routing and scheduling. Tramp ships operate much like taxis following the available demand. Tramp operators can determine some of their demand in advance by entering into long-term contracts and then try to maximise profits from optional voyages found in the spot market. Routing and scheduling a tramp fleet to best utilise fleet capacity according to current demand is therefore an ongoing and complicated problem. Here we add further complexity to the routing and scheduling problem by incorporating voyage separation requirements that enforce a minimum time spread between some voyages. The incorporation of these separation requirements helps balance the conflicting objectives of maximising profit for the tramp operator and minimising inventory costs for the charterer, since these costs increase if similar voyages are not performed with some separation in time. We have developed a new and exact branch-and-price procedure for this problem. We use a dynamic programming algorithm to generate columns and describe a time window branching scheme used to enforce the voyage separation requirements which we relax in the master problem. Computational results show that our algorithm in general finds optimal solutions very quickly and performs much faster compared to an earlier a priori path generation method. Finally, we compare our method to an earlier adaptive large neighbourhood search heuristic and find that on similar-sized instances our approach generally uses less time to find the optimal solution than the adaptive large neighbourhood search method uses to find a heuristic solution.
Scheduling, Maritime transport, Spread requirement, Optimization, Exact algorithms
A Benders Decomposition-Based Matheuristic for the Cardinality Constrained Shift Design Problem
The Shift Design Problem is an important optimization problem which arises when scheduling personnel in industries that require continuous operation. Based on the forecast, required staffing levels for a set of time periods, a set of shift types that best covers the demand must be determined. A shift type is a consecutive sequence of time periods that adheres to legal and union rules and can be assigned to an employee on any day. In this paper we introduce the Cardinality Constrained Shift Design Problem; a variant of the Shift Design Problem in which the number of permitted shift types is bounded by an upper limit. We present an integer programming model for this problem and show that its structure lends itself very naturally to Benders decomposition. Due to convergence issues with a conventional implementation, we propose a matheuristic based on Benders decomposition for solving the problem. Furthermore, we argue that an important step in this approach is finding dual alternative optimal solutions to the Benders subproblems and describe an approach to obtain a diverse set of these. Numerical tests show that the described methodology significantly outperforms a commercial mixed integer programming solver on instances with 1241 different shift types and remains competitive for larger cases with 2145 shift types. On all classes of problems the heuristic is able to quickly find good solutions. © 2016 Elsevier B.V. All rights reserved
A heuristic and hybrid method for the tank allocation problem in maritime bulk shipping

In bulk shipping, ships often have multiple tanks and carry multiple inhomogeneous products at a time. When operating such ships it is therefore a major challenge to decide how to best allocate cargoes to available tanks while taking into account tank capacity, safety restrictions, ship stability and strength as well as other operational constraints. The problem of finding a feasible solution to this tank allocation problem has been shown to be NP-Complete. We approach the problem on a tactical level where requirements for computation time are strict while solution quality is less important than simply finding a feasible solution. We have developed a heuristic that can efficiently find feasible cargo allocations. Computational results show that it can solve 99% of the considered instances within 0.4 s and all of them if allowed longer time. We have also modified an optimality based method from the literature. The heuristic is much faster than this modified method on the vast majority of considered instances. However, the heuristic struggles on two instances which are relatively quickly solved by the modified optimality based method. These two methods therefore complement each other nicely and so, we have created a hybrid method that first runs the heuristic and if the heuristic fails to solve the problem, then runs the modified optimality based method on the parts of the problem that the heuristic did not solve. This hybrid method cuts between 90 and 94% of the average running times compared to the other methods and consistently solves more instances than the other methods within any given time limit. In fact, this hybrid method is fast enough to be used in a tactical setting.

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ISI indexed (2013): ISI indexed yes
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BFI (2012): BFI-level 1
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ISI indexed (2012): ISI indexed yes
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BFI (2011): BFI-level 1
Scopus rating (2011): SJR 2.472 SNIP 2.495 CiteScore 3.05
ISI indexed (2011): ISI indexed yes
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BFI (2010): BFI-level 1
Scopus rating (2010): SJR 2.449 SNIP 2.489
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 1
Scopus rating (2009): SJR 2.386 SNIP 2.405
Web of Science (2009): Indexed yes
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Scopus rating (2008): SJR 2.246 SNIP 2.325
Web of Science (2008): Indexed yes
Scopus rating (2007): SJR 2.058 SNIP 2.568
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Scopus rating (2006): SJR 1.441 SNIP 2.313
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Scopus rating (2003): SJR 1.052 SNIP 1.574
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Scopus rating (2000): SJR 0.909 SNIP 0.866
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An adaptive large neighborhood search procedure applied to the dynamic patient admission scheduling problem

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BFI (2015): BFI-level 2
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BFI (2014): BFI-level 2
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Scopus rating (2013): SJR 0.722 SNIP 1.706 CiteScore 2.57
ISI indexed (2013): ISI indexed yes
BFI (2012): BFI-level 2
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ISI indexed (2012): ISI indexed yes
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Scopus rating (2011): SJR 0.54 SNIP 1.515 CiteScore 2.29
ISI indexed (2011): ISI indexed yes
BFI (2010): BFI-level 2
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Scopus rating (2009): SJR 0.748 SNIP 1.897
BFI (2008): BFI-level 1
Scopus rating (2008): SJR 1.017 SNIP 2.103
Scopus rating (2007): SJR 1.021 SNIP 2.391
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Scopus rating (2004): SJR 0.52 SNIP 1.81
Web of Science (2004): Indexed yes
Scopus rating (2003): SJR 0.758 SNIP 1.756
Web of Science (2003): Indexed yes
Scopus rating (2002): SJR 0.571 SNIP 1.145
Web of Science (2002): Indexed yes
Scopus rating (2001): SJR 0.839 SNIP 1.982
Scopus rating (2000): SJR 0.813 SNIP 1.716
An applied optimization based method for line planning to minimize travel time

The line planning problem in rail is to select a number of lines from a potential pool which provides sufficient passenger capacity and meets operational requirements, with some objective measure of solution line quality. We model the problem of minimizing the average passenger system time, including frequency-dependent estimates for switching between lines, working with the Danish rail operator DSB and data for Copenhagen commuters. We present a multi-commodity flow formulation for the problem of freely routing passengers, coupled to discrete line-frequency decisions selecting lines from a predefined pool. We show results directly applying this model to a Copenhagen commuter rail problem.

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A new approach to the Container Positioning Problem

In this paper the Container Positioning Problem is revisited. This problem arises at busy container terminals and requires one to minimize the use of block cranes in handling the containers that must wait at the terminal until their next means of transportation. We propose a new Mixed Integer Programming model that not only improves on earlier attempts at this problem, but also better reflects reality. In particular, the proposed model adopts a preference to reshuffle containers in line with a just-in-time concept, as it is assumed that data is more accurate the closer to a container’s scheduled departure the time is. Other important improvements include reduction in the model size, and the ability of the model to consider containers initially at the terminal. In addition, we describe several classes of valid inequalities for this new formulation and present a rolling horizon based heuristic for solving larger instances of the problem. We show that this new formulation drastically outperforms previous attempts at the problem through a direct comparison on instances available in the literature. Furthermore, we also show that the rolling horizon based heuristic can further reduce the solution time on the larger of these instances as well as find acceptable solutions to much bigger, artificially generated instances.

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Efficiency and Robustness in Railway Operations

Passenger railway transport is an effective means of providing high capacity transport that is energy efficient and has low emissions. As the population of Denmark grows and there is an increased request for mobility, there is a need for railway services offering greater capacity and more reliability. Offering these services presents a challenging sequence of planning problems for operators. These range from problems considered on a daily basis to planning for years in the future, with different problems interacting and influencing each other.

Operations research methods can be used to effectively model, investigate,
and solve railway planning problems. Despite advances in computational power these large problems are still challenging to solve, especially as more modelling detail is sought. Within a Danish context this thesis seeks to apply operations research methods to different planning problems beyond past approaches, and where applicable, investigate solution methods that place more focus on the passenger and passenger experience. To cater to the growing demand for rail transport, and compete with different modes of transport, Danish railway operators must offer a consistent, reliable service, that is well planned from both a passenger and operator perspective. This thesis therefore considers different planning problems within passenger railway considering robustness of the system, and efficiency and optimality from the point of view of the passenger or operator.

The contributions of the thesis are in the investigation of robustness in railway, the application of optimization to a number of railway planning problems, and a detailed consideration of the specific concerns of Danish railway services. These contributions are summarised in the introductory chapter, and in the latter part of the thesis are given in each chapter.

Finding equidistant nondominated points for biobjective mixed integer programs
The nondominated frontier of a multiobjective optimization problem can be overwhelming to a decision maker, as it is often either exponential or in finite in size. Instead, a representation of this set in the form of a small sample of points is often preferred. In this paper we present a new biobjective criterion space search method for generating a small set of equidistant points based on the space division idea behind Voronoi diagrams. The motivation for this method stems from the finding that there exists a dual relationship between the well-established quality measures of coverage and uniformity, and that a set of equidistant points closes the gap. The method is easy to implement, and relies only on the availability of a black-box solver. We show on a benchmark set of biobjective mixed integer programming instances that the method outperforms the state of the art with respect to both coverage and uniformity.
Joint overbooking and seat allocation for fare families
Revenue Management Systems (RMS) traditionally solve the seat allocation problem separately from the overbooking problem. Overbooking is managed by inflating the authorization levels obtained from seat allocation by various heuristics. This approach although suboptimal, is necessitated because of the complexity and dimensionality of the Dynamic Program (DP), which prohibits computation for realistic size problems.

We review several DP models developed for seat-allocation and overbooking over a time span of 40 years, reflecting changed business environments. In this report we link these models together by means of two transformations: The marginal revenue transformation of Fiig et al. [2010] and the equivalence charging scheme of Subramanian et al. [1999]. These transformations enable us to transform the joint seat allocation and overbooking problem for fare family fare structures into an equivalent independent demand model, which is readily solved. The resulting availability control can easily be implemented in existing RMS.

Planning of Midwives
At a hospital in Denmark around 40 midwives support the pregnancy of approx. 6000 pregnant women every year. Their role is to monitor the pregnancies and prepare the women for labour. Based on the due date of a woman, authority guidelines prescribe specific and mostly rather narrow time windows within which the pregnant woman should have consultations with a midwife. Therefore, once a pregnant woman enters the system, here sequence of consultations for the time period until labour is fairly fixed. There is a clear goal that, as far as possible, each pregnant woman should see the same midwife at every consultation. Every week the newly arrived pregnant women are assigned an arbitrary free time slot belonging to a specific midwife. In turn this midwife is expected to have consultations with this woman in specific weeks according to the authority guidelines. This random assignment of pregnant woman to specific midwives, without any concern to the midwives' future schedules, means that each midwife has a very unbalanced workload over the year. Furthermore, it means that there is an imbalance between the workloads of the different midwives. The aim of this project is therefore to devise a method that can make a fair distribution of pregnant women among the midwives. The distribution should result in a balanced work load for each midwife and a balanced work load among the midwives while at the same time making sure that the time windows for consultations are not violated.
A Benders decomposition-based Matheuristic for the Cardinality Constrained Shift Design Problem

The Shift Design Problem is an important optimization problem which arises when scheduling personnel in industries that require continuous operation. Based on the forecast, required staffing levels for a set of time periods, a set of shift types that best covers the demand must be determined. A shift type is a consecutive sequence of time periods that adheres to legal and union rules and can be assigned to an employee on any day. In this paper we introduce the Cardinality Constrained Shift Design Problem; a variant of the Shift Design Problem in which the number of permitted shift types is bounded by an upper limit. We present an Integer Programming model for this problem and show that it's structure lends itself very naturally to Benders decomposition. Due to convergence issues with a conventional implementation, we propose a matheuristic based on Benders decomposition for solving the problem. Furthermore, we argue that an important step in this approach is finding dual alternative optimal solutions to the Benders subproblems and describe an approach to obtain a diverse set of these. Numerical tests show that the described methodology significantly outperforms a commercial Mixed Integer Programming solver on instances with 1241 different shift types and remains competitive for larger cases with 2145 shift types. On all classes of problems the heuristic is able to quickly nd good solutions.

General information
State: Published
Organisations: Department of Management Engineering, Management Science, University of Southern Denmark
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Publication information
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Scheduling, Shift design, Integer programmning, Benders decomposition
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Aircraft Stand Allocation with Associated Resource Scheduling

An aircraft turn-round refers to the set of processes taking place from when an aircraft parks at its arrival stand until the time it departs from its departure stand. When handling a turn-round, the different processes involved (arrival, disembarkation of passengers, cleaning, etc.) require different ground handling resources (taxiways, aircraft stands, gates, etc) at different times. Each resource can be claimed by at most one turn-round at a time. The aircraft stand allocation problem with associated resource scheduling is the problem of allocating the required ground handling resources to handle a given set of aircraft turn-rounds. We develop a set packing-based model formulation of the problem which is both flexible in the sense that it can encapsulate any type of resource required during the handling of a turn-round and strong in the sense that conflicts that occur when two or more turn-rounds simultaneously claim the same resource are handled implicitly. To solve the model, a heuristic based on linear programming is developed. The heuristic iteratively solves a relaxed, restricted version of the problem, adding extra variables at each iteration if needed. The additional variables are identified by a cost-based partial enumeration of the possible variables for each turn-round and the heuristic stops when the first feasible solution is encountered. The heuristic has been tested on real data from Copenhagen Airport with a special focus on tactical day-to-day planning. The results show that the method generates high-quality feasible solutions within reasonable time for tactical planning.

General information
State: Published
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Publisher: DTU Management Engineering
Original language: English
A New Approach to the Container Positioning Problem
In this paper the Container Positioning Problem is revisited. This problem arises at busy container terminals and requires one to minimize the use of block cranes in handling the containers that must wait at the terminal until their next means of transportation. We propose a new Mixed Integer Programming model that not only improves on earlier attempts at this problem, but also better reflects reality. In particular, the proposed model adopts a preference to reshuffle containers in line with a just-in-time concept, as it is assumed that data is more accurate the closer to a container’s scheduled departure the time is. Other important improvements include a reduction in the model size, and the ability of the model to consider containers initially at the terminal. In addition, we describe several classes of valid inequalities for this new formulation and present a rolling horizon based heuristic for solving larger instances of the problem. We show that this new formulation drastically outperforms previous attempts at the problem through a direct comparison on instances available in the literature. Furthermore, we also show that the rolling horizon based heuristic can further reduce the solution time on the larger of these instances as well as find acceptable solutions to much bigger, artificially generated, instances.

General information
State: Published
Organisations: Department of Management Engineering, Management Science, Maersk Line, Accenture, University of Auckland
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Original language: English
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An integrated rolling stock planning model for the Copenhagen suburban passenger railway
A central issue for operators of passenger railways is providing sufficient number of seats for passengers while at the same time minimising operating costs. This is the task of rolling stock planning. Due to the large number of practical, railway specific requirements that a rolling stock plan has to take into account, rolling stock plans are often constructed in a step-by-step manner, taking some requirements into consideration in each step. This may make it difficult in the final step to produce a plan that is feasible with regard to all of the requirements and at the same time economically attractive. This paper proposes an integrated rolling stock planning model that simultaneously takes into account all practical requirements for rolling stock planning at DSB S-tog, the suburban passenger train operator of the City of Copenhagen. The model is then used to improve existing rolling stock plans using a hill climbing heuristic. Experiments show that the heuristic used in the integrated rolling stock planning model is able to produce feasible solutions within minutes of computation time starting from infeasible rolling stock plans. Furthermore, the heuristic is able to improve the economic attractiveness of typical rolling stock plans with an average of 2%.

General information
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Organisations: Department of Management Engineering, Management Science, DSB, IBM Research
Authors: Thorlacius, P. (Ekstern), Larsen, J. (Intern), Laumanns, M. (Ekstern)
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A central issue for operators of passenger railways is providing sufficient number of seats for passengers while at the same time minimising operating costs. This is the task of rolling stock planning. Due to the large number of practical, railway specific requirements that a rolling stock plan has to take into account, rolling stock plans are often constructed in a step-by-step manner, taking some requirements into consideration in each step. This may make it difficult in the final step to produce a plan that is feasible with regard to all of the requirements and at the same time economically attractive.

This paper proposes an integrated rolling stock planning model that simultaneously takes into account all practical requirements for rolling stock planning at DSB S-tog, the suburban passenger train operator of the City of Copenhagen. The model is then used to improve existing rolling stock plans using a hill climbing heuristic. Experiments show that the heuristic used in the integrated rolling stock planning model is able to produce feasible solutions within minutes of computation time starting from infeasible rolling stock plans. Furthermore, the heuristic is able to improve the economic attractiveness of typical rolling stock plans with an average of 2%.

An optimization based method for line planning to minimize travel time

The line planning problem is to select a number of lines from a potential pool which provides sufficient passenger capacity and meets operational requirements, with some objective measure of solution line quality. We model the problem of minimizing the average passenger system time, including frequency-dependent estimates for switching between lines, working with the Danish rail operator DSB and data for Copenhagen commuters. We present a multi-commodity ow formulation for the problem of freely routing passengers, coupled to discrete line-frequency decisions selecting lines from a predefined pool. We show results directly applying this model to the Copenhagen commuter rail problem.
Mitigation of airspace congestion impact on airline networks

In recent years European airspace has become increasingly congested and airlines can now observe that en-route capacity constraints are the fastest growing source of flight delays. In 2010 this source of delay accounted for 19% of all flight delays in Europe and has been increasing with an average yearly rate of 17% from 2005 to 2010. This paper suggests and evaluates an approach to how disruption management can be combined with flight planning in order to create more proactive handling of the kind of disruptions, which are caused by congested airspace. The approach is evaluated using data from a medium size European carrier and estimates a lower bound saving of several million USD.
Reactive Robustness and Integrated Approaches for Railway Optimization Problems

Planning railway operations is not a simple task as it entails solving multiple interdependent optimization problems. These problems have been subject to study in the literature for the last few decades, and are still profoundly researched. The robustness of a plan or schedule denotes the ability to absorb or withstand unexpected events such as delays. Making robust plans is central in order to maintain a safe and timely railway operation. This thesis focuses on reactive robustness, i.e., the ability to react once a plan is rendered infeasible in operation due to disruptions. In such time-critical situations, new plans must be found quickly. Integration of the different planning problems is also considered in this thesis as these problems are strongly interdependent in many cases. In contrast, finding feasible plans for each problem in isolation can lead to an overall infeasibility, e.g., during a disruption the updated timetable may be impossible to realize due to the lack of rolling stock units at certain positions. It is important to avoid creating problems for later or subsequent planning stages.

Several railway problems are studied in this thesis. The main contributions are summarized in individual chapters, some of which are papers that have been submitted to international scientific journals in operations research. The problems have been formulated as optimization problems and solution methods have been proposed to solve them using optimization theory and various solution techniques. In collaboration with industry and academic partners real-life and realistic data has been used to benchmark and test the solution methods. A central actor and theme of the thesis is the rolling stock running on the railway networks. A public timetable is given, and in order to service the departures and passengers a rolling stock schedule (or circulation) is sought that provides the best compromise between operational cost, robustness, contract requirements and passenger satisfaction. In between train services the rolling stock units must be parked in the available depots. As trains cannot overtake each other easily, special attention must be given to avoid conflicting movements.

Furthermore, rolling stock units are heavy and consume a considerable amount of energy in operation; with proper optimization tools a significant amount of the energy can be saved. A prompt optimization of individual train journeys helps the driver to drive efficiently and enhances robustness in a realistic (dynamic) environment. Four international scientific prizes have been awarded for distinct parts of the research during the course of this PhD project. The first prize was awarded for work during the ‘2014 RAS Problem Solving Competition’, where a freight yard optimization problem was considered. The second junior (PhD) prize was awarded for the work performed in the ‘ROADEF/EURO Challenge 2014: Trains don’t vanish!’ where the planning of rolling stock movements at a large station was considered. An honorable mention (and second place) was awarded in recognition for excellent work in the ‘Discrete Optimization Challenge’, where the aim was to minimize energy consumption in timetables. Finally, a second place was awarded in the ‘2015 RAS Student Paper Award’, where a comparison of solution methods for planning shunting yard movements was considered.
Simultaneously Recovering Rolling Stock Schedules and Depot Plans Under Disruption

In this paper we consider two important railway optimization problems. In particular, we focus on the Rolling Stock Rescheduling problem and the Depot Replanning problem, respectively. We present an integrated framework for solving these two problems simultaneously, and show that it is fast enough to be applied in a disruption recovery setting. Furthermore, we provide a comparison of several solution strategies to the Train Unit Parking Problem, and, by way of an example prove the heuristic nature of a previously proposed optimal approach. We analyse the performance of the proposed methodology on a number of artificial data sets as well as several real-life case studies provided by DSB Stog, a suburban train operator in the greater Copenhagen area.

Solving the selective multi-category parallel-servicing problem

In this paper, we present a new scheduling problem and describe a shortest path-based heuristic as well as a dynamic programming-based exact optimization algorithm to solve it. The selective multi-category parallel-servicing problem arises when a set of jobs has to be scheduled on a server (machine) with limited capacity. Each job requests service in a prespecified time window and belongs to a certain category. Jobs may be serviced partially, incurring a penalty; however, only jobs of the same category can be processed simultaneously. One must identify the best subset of jobs to process in each time interval of a given planning horizon, while respecting the server capacity and scheduling requirements. We compare the proposed solution methods with a Mixed Integer Linear Programming (MILP) formulation and show that the dynamic programming approach is faster when the number of categories is large, whereas the MILP can be solved faster when the number of categories is small.
Tramp Ship Routing and Scheduling - Models, Methods and Opportunities

In tramp shipping, ships operate much like taxis, following the available demand. This contrasts liner shipping where vessels operate more like busses on a fixed route network according to a published timetable. Tramp operators can enter into long term contracts and thereby determine some of their demand in advance. However, the detailed requirements of these contract cargoes can be subject to ongoing changes, e.g. the destination port can be altered. For tramp operators, a main concern is therefore the efficient and continuous planning of routes and schedules for the individual ships. Due to mergers, pooling, and collaboration efforts between shipping companies, the fleet sizes have grown to a point where manual planning is no longer adequate in a market with tough competition and low freight rates. The aim of this paper is to
provide a comprehensive introduction to tramp ship routing and scheduling. This includes a review on existing literature, modelling approaches, solution methods as well as an analysis of the current status and future opportunities of research within tramp ship routing and scheduling. We argue that rather than developing new solution methods for the basic routing and scheduling problem, focus should now be on extending this basic problem to include additional real-world complexities and develop suitable solution methods for those extensions. Such extensions will enable more tramp operators to benefit from the solution methods while simultaneously creating new opportunities for operators already benefitting from existing methods.

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Authors: Vilhelmsen, C. (Intern), Larsen, J. (Intern), Lusby, R. M. (Intern)
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A Branch-and-Price Framework for Railway Rolling Stock Rescheduling During Disruptions
Rescheduling rolling stock during a disruption is a passenger railway optimization problem. In current practice this is typically optimized manually despite the high complexity and high runtime requirements of the task. In this paper we propose a path-based mathematical formulation that is solved using column generation in a complete Branch-and-Price framework. In contrast to flow-based approaches our formulation is more easily extended to handle certain families of constraints, such as train unit maintenance restrictions. We benchmark the framework against real-life instances provided by the suburban railway operator in Copenhagen (DSB S-tog). In combination with a lower bound method we show that near-optimal solutions can be found within a few seconds during a disruption. In addition we show that framework is also able to find solution within a few minutes for non-disturbed timetables.

General information
State: Published
Organisations: Department of Management Engineering, Management Science
Authors: Haahr, J. T. (Intern), Lusby, R. M. (Intern), Larsen, J. (Intern), Pisinger, D. (Intern)
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A_Branch_and_Price_Framework.pdf
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Publication: Research › Report – Annual report year: 2014

A column generation approach for solving the patient admission scheduling problem
This paper addresses the Patient Admission Scheduling (PAS) problem. The PAS problem entails assigning elective patients to beds, while satisfying a number of hard constraints and as many soft constraints as is possible, and arises at all planning levels for hospital management. There exist a few, different variants of this problem. In this paper we consider one such variant and propose an optimization-based heuristic building on branch-and-bound, column generation, and dynamic constraint aggregation to solve it. We achieve tighter lower bounds than previously reported in the literature and, in addition, we are able to produce new best known solutions for five out of twelve instances from a publicly available repository. © 2013 Elsevier B.V. All rights reserved.

General information
A Heuristic and Hybrid Method for the Tank Allocation Problem in Maritime Bulk Shipping

Many bulk ships have multiple tanks and can thereby carry multiple inhomogeneous products at a time. When operating such ships it is therefore a major challenge to decide how to best allocate cargoes to available tanks while taking into account tank capacity, safety restrictions, ship stability and strength as well as other operational constraints into account. The complexity of the allocation problem varies with the number of tanks and the number and type of different products transported at the same time, and the problem of finding a feasible solution has been shown to be NP-Complete. The Tank Allocation Problem (TAP) as described above is an operational planning problem but it also arises as a subproblem in tactical planning when routing bulk ship sets. For each considered route, the TAP must be solved to assess route feasibility with respect to stowage. If the routing problem is solved in a way that requires assessment of numerous routes, as for instance in column generation and local search based methods, the solution time for the entire procedure will only be acceptable if the TAP can be solved efficiently. We consider the TAP from a tactical perspective where the main objective is to quickly assess feasibility of a given ship route. We have developed a randomised heuristic for efficiently finding feasible allocations and computational results show that it can solve 99% of the considered instances within 0.5 seconds and all of them if allowed longer time. The heuristic is designed to work as an efficient subproblem solver and in such a setting with running times below e.g. 5 seconds, the heuristic clearly outperforms an earlier method by consistently solving instances and effectively cutting 84% of the average running time. Furthermore, we have combined our heuristic with a modified version of the earlier method to derive a hybrid method that can efficiently solve all instances. Compared to the earlier method, this hybrid method cuts 93% of the average running times and consistently solves more instances than the other method within any given time limit.

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Organisations: Department of Management Engineering, Management Science
Authors: Vilhelmsen, C. (Intern), Larsen, J. (Intern), Lusby, R. M. (Intern)
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solves more instances than the other methods within any given time limit. In fact, this hybrid method is fast enough to be used in a tactical setting.

**General information**
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Publication: Research › Report – Annual report year: 2014

**A Hybrid Column Generation approach for an Industrial Waste Collection Routing Problem**
This paper presents a practical roll-on/roll-off routing (ROROR) problem arising in the collection of industrial waste. Skip containers, which are used for the waste collection, need to be distributed between, and collected from, a set of customers. Full containers must be driven to dump sites, while empty containers must be returned to the depot to await further assignments. Unlike, the traditional ROROR problem, where vehicles may transport one skip container at a time regardless of whether it is full or not, we consider cases in which a vehicle can transport up to eight containers, at most two of which can be full. We propose a Generalized Set Partitioning formulation of the problem and describe a hybrid column generation procedure to solve it. A fast Tabu Search heuristic is used to generate new columns. The proposed methodology is tested on nine data sets, four of which are actual, real-world problem instances. Results indicate that the hybrid column generation outperforms a purely heuristic approach in terms of both running time and solution quality. High quality solutions to problems containing up to 100 orders can be solved in approximately 15 minutes.

**General information**
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Authors: Hauge, K. (Ekstern), Larsen, J. (Intern), Lusby, R. M. (Intern), Krapper, E. (Ekstern)
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Scopus rating (2016): SJR 1.542 SNIP 1.773 CiteScore 3.41
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Scopus rating (2015): SJR 1.468 SNIP 1.931 CiteScore 3.13
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 1.446 SNIP 1.993 CiteScore 2.8
Web of Science (2014): Indexed yes
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Scopus rating (2013): SJR 1.577 SNIP 2.097 CiteScore 2.81
Allocation of Ground Handling Resources at Copenhagen Airport

Operating an airport is a very complex task involving many stakeholders. The primary role of airport management is to ensure that the airport provides sufficient capacity in all operational areas and that all the companies carrying out business at the airport have the best possible working conditions. Moreover, management must ensure that the airport stays competitive and that its business goals are met to the greatest possible extent.

The European Organization for the Safety of Air Navigation (EUROCONTROL) expects demand for air services in Europe to double by 2030 and identifies airport capacity as a potential bottleneck that may slow this growth. Many European airports are already operating at the limit of their capacity; moreover, they are under competitive pressure from both nearby airports and fast-growing mega-hubs in the Middle East. Providing efficient and reliable airport operations is imperative for the viability and continued development of both individual airports and the air transportation industry in general.

This thesis gives a general introduction to the management of airport operations. It describes the main airport processes and optimization problems that these processes give rise to. The primary focus is on ground handling resource allocation problems, it looks in detail at the following problems: the check-in counter allocation problem, the baggage make-up position problem, the tactical stand and gate allocation problem, the operational stand and gate allocation problem, and the taxiway route allocation problem. Although these problems arise from different airport processes and involve different stakeholders, they share some characteristics and can be formulated as variants of the same mathematical model.

Many real-world aspects must be taken into consideration when solving airport optimization problems; the models and solutions that are developed must be able to meet the needs of airlines to the greatest possible extent. They must be easy to configure and efficient to solve. For three of the problems considered here, real-world restrictions reduce the number of possible variables to such an extent that the problem can be efficiently solved to optimality with modern, state-of-the-art MIP solvers. For the remaining problems, an LP based heuristic was developed. The method iteratively solves a restricted LP relaxed version of the problem and exploits expert knowledge to generate appropriate initial variables, enabling the heuristic to efficiently find near-optimal and operationally valid solutions.

The work described in this thesis was carried out in the context of an Industrial PhD project at Copenhagen Airport in collaboration with the Technical University of Denmark. It contributes to both the introduction and definition of various
ground handling resource allocation problems, and proposes a mathematical formulation of the problems. These contributions are presented in four scientific papers and one technical report, which are included. All the models and solution methods described here are currently implemented and used in various settings at Copenhagen Airport. These include weekly operational planning of check-in counter allocation and long-term capacity/demand analyses of the airport’s stands and gates.

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**General information**

State: Published  
Organisations: Department of Management Engineering  
Authors: Justesen, T. F. (Intern), Dohn, A. H. (Intern), Larsen, J. (Intern)  
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Original language: English  
Main Research Area: Technical/natural sciences  
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**Room Allocation Optimisation at the Technical University of Denmark**

As at many other universities the Technical University of Denmark (DTU) faces the challenge of solving a case of the curriculum based university course timetabling problem (CUCTT) multiple times a year. However, there are some slight modications to the CUCTT problem usually described in the literature. One of the major dierence is that the assignment of the courses to specic time slots are predetermined and cannot be subject to changes. This is a decision made by the administration since this takes away the issue of course collisions, e.g. when two courses sharing a student are allocated at overlapping time slots, since the students are to ensure by themselves that their courses do not overlap. The problem was rst considered in the masters’ thesis [1] and the project here is an extension of the work done in that thesis.

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**Tramp Ship Routing and Scheduling - Incorporating Additional Complexities**

In tramp shipping, ships operate much like taxies, following the available demand. This contrasts liner shipping where vessels operate more like busses on a fixed route network according to a published timetable. Tramp operators can enter into long term contracts and thereby determine some of their demand in advance. However, the detailed requirements of these contract cargoes can be subject to ongoing changes, e.g. the destination port can be altered. For tramp operators, a main concern is therefore the efficient and continuous planning of routes and schedules for the individual ships. Due to mergers, pooling, and collaboration efforts between shipping companies, the fleet sizes have grown to a point where manual planning is no longer adequate in a market with tough competition and low freight rates. This thesis therefore aims at developing new mathematical models and solution methods for tramp ship routing and scheduling problems. This is done in the context of Operations Research, a research field that has achieved great success within optimisation-based planning for vehicle routing problems and in many other areas. The first part of this thesis contains a comprehensive introduction to tramp ship routing and scheduling. This includes modelling approaches, solution methods as well as an
analysis of the current status and future direction of research within tramp ship routing and scheduling. We argue that rather than developing new solution methods for the basic routing and scheduling problem, focus should now be on extending this basic problem to include additional complexities and develop suitable solution methods for those extensions. Such extensions will enable more tramp operators to benefit from the solution methods while simultaneously creating new opportunities for operators already benefitting from existing methods. The second part of this thesis therefore deals with three distinct ways of extending the basic tramp ship routing and scheduling problem to include additional complexities. First, we explore the integration of bunker planning, then we discuss a possible method for incorporating tank allocations and finally, we consider the inclusion of voyage separation requirements. For each of these extensions, we develop a new solution method and discuss the impact of incorporating these additional complexities. Aside from a comprehensive introduction to tramp ship routing and scheduling, the main contribution of this thesis is the exploration of the three aforementioned extensions of the basic tramp ship routing and scheduling problem. The work on these three distinct extensions together represent a diverse collection of both problems and solution methods within tramp ship routing and scheduling.

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Publication: Research › Ph.D. thesis – Annual report year: 2015

Tramp ship routing and scheduling with integrated bunker optimization
A tramp ship operator typically has some contracted cargoes that must be carried and seeks to maximize prot by carrying optional cargoes. Hence, tramp ships operate much like taxis following available cargoes and not according to a fixed route network and itinerary as liner ships. Marine fuel is referred to as bunker and bunker costs constitute a significant part of the daily operating costs. There can be great variations in bunker prices across bunker ports so it is important to carefully plan bunkering for each ship. As ships operate 24 hours a day, they must refuel during operations. Therefore, route and schedule decisions affect the options for bunkering. Current practice is, however, to separate the two planning problems by first constructing fleet schedules and then plan bunkering for these fixed schedules. In this paper we explore the effects of integrating bunker planning in the routing and scheduling phase and present a mixed integer programming formulation for the integrated problem of optimally routing, scheduling and bunkering a tramp fleet. Aside from the integration of bunker, this model also extends standard tramp formulations by using load dependent costs, speed and bunker consumption. We devise a solution method based on column generation with a dynamic programming algorithm to generate columns. The method is heuristic mainly due to a discretization of the continuous bunker purchase variables. We show that the integrated planning approach can increase prots and that the decision of which cargoes to carry and on which ships is affected by the bunker integration and by changes in the bunker prices.

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Ratings:
BFI (2018): BFI-level 1
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 1
A Column Generation Approach for Solving the Patient Admission Scheduling Problem

This paper addresses the Patient Admission Scheduling (PAS) problem. The PAS problem deals with assigning elective patients to beds, satisfying a number of soft and hard constraints. The problem can be seen as part of the functions of hospital management at an operational level. There exists a small number of different variants on this problem. We propose an optimization-based heuristic building on branch-and-bound, column generation, and dynamic constraint aggregation for one of the variants. We achieve tighter bounds than previously reported in the literature, and in addition we are able to produce new best solutions for five out of six instances from a publicly available repository.

General information
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Organisations: Department of Management Engineering, Management Science, University of Southern Denmark
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A_Column_Generation_Approach.pdf
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Publication: Research - peer-review › Journal article – Annual report year: 2013

A set packing inspired method for real-time junction train routing

Efficiently coordinating the often large number of interdependent, timetabled train movements on a railway junction, while satisfying a number of operational requirements, is one of the most important problems faced by a railway company. The most critical variant of the problem arises on a daily basis at major railway junctions where disruptions to rail traffic make the planned schedule-routing infeasible and rolling stock planners are forced to re-schedule/re-route trains in order to recover feasibility. The dynamic nature of the problem means that good solutions must be obtained quickly. In this paper we describe a set packing inspired formulation of this problem and develop a branch-and-price based solution approach. A real life test instance arising in Germany and supplied by the major German railway company, Deutsche Bahn, indicates the efficiency of the proposed approach by confirming that practical problems can be solved to within a few percent of optimality in reasonable time.

General information
State: Published
Organisations: Department of Management Engineering, Management Science, University of Auckland
Authors: Lusby, R. M. (Intern), Larsen, J. (Intern), Ehrbott, M. (Ekstern), Ryan, D. M. (Ekstern)
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Publication date: 2013
Routing and Scheduling in Tramp Shipping - Integrating Bunker Optimization

A tramp ship operator typically has some contracted cargoes that must be carried and seeks to maximize profit by carrying optional cargoes. Hence, tramp ships operate much like taxis following available cargoes and not according to a fixed route network and itinerary as liner ships. Marine fuel is referred to as bunker fuel or simply bunker and bunker costs constitute a significant part of the daily operating costs. There can be great variations in bunker prices across bunker ports so it is important to carefully plan bunkering for each ship. As ships operate 24 hours a day, they must refuel during operations. Therefore, route and schedule decisions affect the options for bunkering. Current practice is, however, to separate the two planning problems by first constructing fleet schedules and then plan bunkering for these fixed schedules. In this paper we explore the effects of integrating bunker planning in the routing and scheduling phase and present a mixed integer programming formulation for the integrated problem of optimally routing, scheduling and bunkering a tramp fleet. Aside from the integration of bunker, this model also extends standard tramp formulations by using load dependent costs, speed and bunker consumption. We devise a solution method based on column generation with a dynamic programming algorithm to generate columns. The method is heuristic mainly due to a discretization of the continuous bunker purchase variables. We show that the integrated planning approach can increase profits and that the decision of which cargoes to carry and on which ships is affected by the bunker integration and by changes in the bunker prices.
Solving the Selective Multi-Category Parallel-Servicing Problem

In this paper we present a new scheduling problem and describe a shortest path based heuristic as well as a dynamic programming based exact optimization algorithm to solve it. The Selective Multi-Category Parallel-Servicing Problem (SMCPSP) arises when a set of jobs has to be scheduled on a server (machine) with limited capacity. Each job requests service in a prespecified time window and belongs to a certain category. Jobs may be serviced partially, incurring a penalty; however, only jobs of the same category can be processed simultaneously. One must identify the best subset of jobs to process in each time interval of a given planning horizon while respecting the server capacity and scheduling requirements. We compare the proposed solution methods with a MILP formulation and show that the dynamic programming approach is faster when the number of categories is large, whereas the MILP can be solved faster when the number of categories is small.

General information
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Organisations: Department of Management Engineering, Management Science, University of Southern Denmark
Authors: Range, T. M. (Ekstern), Lusby, R. M. (Intern), Larsen, J. (Intern)
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The Rolling Stock and Depot Recovery Problem

General information
State: Published
Organisations: Department of Management Engineering, Management Science
Authors: Haahr, J. T. (Intern), Lusby, R. M. (Intern), Larsen, J. (Intern), Pisinger, D. (Intern)
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Main Research Area: Technical/natural sciences
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The Tank Allocation Problem in Bulk Shipping

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State: Published
Organisations: Department of Management Engineering, Management Science
Authors: Vilhelmsen, C. (Intern), Lusby, R. M. (Intern), Larsen, J. (Intern)
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Event: Abstract from 4th International Conference on Computational Logistics, Copenhagen, Denmark.
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Electronic versions:
The_Tank_Allocation_Problem.pdf
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Publication: Research - peer-review › Conference abstract for conference – Annual report year: 2013
A column generation-based heuristic for rostering with work patterns

This paper addresses the Ground Crew Rostering Problem with Work Patterns, an important manpower planning problem arising in the ground operations of airline companies. We present a cutting stock-based integer programming formulation of the problem and describe a powerful heuristic decomposition approach, which utilizes column generation and variable fixing, to construct efficient rosters for a six-month time horizon. The time horizon is divided into smaller blocks, where overlaps between the blocks ensure continuity. The proposed methodology is able to circumvent one step of the conventional roster construction process by generating rosters directly based on the estimated workload. We demonstrate that this approach has the additional advantage of being able to easily incorporate robustness in the roster. Computational results on real-life instances confirm the efficiency of the approach.

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Organisations: Operations Research, Department of Management Engineering, University of Southern Denmark
Authors: Lusby, R. M. (Intern), Dohn, A. H. (Intern), Range, T. M. (Ekstern), Larsen, J. (Intern)
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Scopus rating (2016): SJR 1.004 SNIP 1.052 CiteScore 1.59
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Scopus rating (2014): SJR 1.045 SNIP 1.112 CiteScore 1.34
Web of Science (2014): Indexed yes
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ISI indexed (2011): ISI indexed yes
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Scopus rating (2010): SJR 1.531 SNIP 1.137
BFI (2009): BFI-level 2
Scopus rating (2009): SJR 1.352 SNIP 1.124
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 2
Scopus rating (2008): SJR 1.15 SNIP 1.115
Scopus rating (2007): SJR 0.927 SNIP 1.11
Web of Science (2007): Indexed yes
Scopus rating (2006): SJR 0.866 SNIP 1.132
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Sustainable Disruption Management

The world we live in is globalized. Goods are seldom made in the place where they are used or consumed, and we do increasingly travel to other countries for either business or pleasure. In our everyday lives we rely on well-functioning global transportation systems to continue the standard of living we are enjoying. We rely on airlines being able to transport us safely and efficiently around the globe and may all recall when the Islandic volcano with the difficult name, Eyjafjallajökull, disrupted our ability of doing so.

The backbone of world trade, shipping, does not reach the news in the same way, when operation is disrupted. Never the less, we may recall that the Suez Canal was closed due to riots in Egypt, that the fuel price was impacted by threats of closing of the Strait of Hormuz, and we do from time to time hear about acts of piracy outside the coast of Somalia. All of these events lead to very severe disruptions to transportation systems. Less severe disruptions do, however, also have a significant impact on transportation systems and on most days, an airline or a shipping company will experience some level of disruption. Most often due to weather, but other issues, such as e.g. technical problems or congestions are also typical causes of delays. Returning a transportation system to its original plan of operation is referred to as Disruption Management.

Disruptions are, however, not the only cause of concern to the transportation industry. Fuel is becoming an increasingly expensive resource, and it is being consumed in vast amounts by the transportation industry. The single largest expense for both airlines and shipping companies is fuel, which exceeds both labour costs and capital expenditure.

This thesis addresses how fuel considerations can be taken into account when managing recovery from disruptions. The underlying work of this thesis is carried out as an industrial PhD project in co-operation with the company Jeppesen, which have the airline industry as its primary area of business and the maritime industry as its secondary area. For this reason the thesis has been divided accordingly, with the primary focus being on the airline industry and the secondary being on the maritime industry - more specifically, the liner shipping industry, which in terms of network structure has many similarities with airline networks.

The thesis presents how disruption management fits in to the larger scope of optimization related processes in an airline and provides a brief survey of these. The thesis goes into more detail with disruption management and does as its main contribution describe how this can be combined with flight planning. Flight planning is the calculation of the horizontal and vertical flight path, which an aircraft should follow in order to get from airport A to airport B. The objective of this calculation is typically to minimize fuel consumption, while satisfying airspace regulations. To the knowledge of the author the work in this thesis represents the first papers combining disruption management and flight planning through an integrated optimization approach.

An additional contribution of the thesis is to show how flexible flight speeds can be used to improve recovery from disruptions, while at the same time allowing an airline to trade off fuel costs with passenger delay costs. Experimental results show both large cost savings of 5.7% and very large reductions in passenger misconnections of 66% by applying the approach.

This contribution is carried over to the liner shipping industry, which despite being a different industry and having different constraints than the airlines, has sufficient similarities in network structure to benefit from a similar recovery concept. This work has lead to a successful development of an optimization model for the Vessel Schedule Recovery problem (VSRP), which is an area that has not previously been addressed in published literature. Experiments show up to 58% savings in recovery costs compared to manually realized recovery costs for real-life cases.

The thesis does furthermore describe the airspace structure and how flight planning is carried out within the constraints of this structure. In both the US and Europe the flow of flights between different regions is centrally managed in order to reduce the negative impact of airspace congestions. A final contribution of the thesis is an approach and a model, which combines disruption management with flexible flight trajectories. In a situation, where a specific area of the airspace is congested, this approach can help an airline with a more proactive handling of the kind of disruptions, which are caused
by congested airspace. This is again an area, which has not previously been addressed through an approach combining both flight planning and disruption management. The real-world results show considerable yearly savings of above 5.1 million USD for a medium size airline operating in European airspace, which is significantly affected by airspace congestions.

**General information**

State: Published  
Organisations: Department of Management Engineering, Management Science  
Authors: Vaaben, B. V. (Intern), Hansen, J. (Intern), Larsen, J. (Intern), Altus, S. (Ekstern)  
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BoVaaben_thesis_final_.PDF  
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**The Home Care Crew Scheduling Problem: Preference-based visit clustering and temporal dependencies**

In the Home Care Crew Scheduling Problem a staff of home carers has to be assigned a number of visits to patients’ homes, such that the overall service level is maximised. The problem is a generalisation of the vehicle routing problem with time windows. Required travel time between visits and time windows of the visits must be respected. The challenge when assigning visits to home carers lies in the existence of soft preference constraints and in temporal dependencies between the start times of visits. We model the problem as a set partitioning problem with side constraints and develop an exact branch-and-price solution algorithm, as this method has previously given solid results for classical vehicle routing problems. Temporal dependencies are modelled as generalised precedence constraints and enforced through the branching. We introduce a novel visit clustering approach based on the soft preference constraints. The algorithm is tested both on real-life problem instances and on generated test instances inspired by realistic settings. The use of the specialised branching scheme on real-life problems is novel. The visit clustering decreases run times significantly, and only gives a loss of quality for few instances. Furthermore, the visit clustering allows us to find solutions to larger problem instances, which cannot be solved to optimality.

**General information**

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Organisations: Department of Management Engineering, Management Science  
Authors: Rasmussen, M. S. (Intern), Justesen, T. F. (Intern), Dohn, A. H. (Intern), Larsen, J. (Intern)  
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Scopus rating (2016): CiteScore 3.83 SJR 2.505 SNIP 2.339  
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Optimisation-Based Solution Methods for Set Partitioning Models

The scheduling of crew, i.e. the construction of work schedules for crew members, is often not a trivial task, but a complex puzzle. The task is complicated by rules, restrictions, and preferences. Therefore, manual solutions as well as solutions from standard software packages are not always sufficient with respect to solution quality and solution time. Enhancement of the overall solution quality as well as the solution time can be of vital importance to many organisations. The fields of operations research and mathematical optimisation deal with mathematical modelling of difficult scheduling problems (among other topics). The fields also deal with the development of sophisticated solution methods for these mathematical models.

This thesis describes the set partitioning model which has been widely used for modelling crew scheduling problems. Integer properties for the set partitioning model are shown, and exact and optimisation-based heuristic solution methods for the model are described. All these methods are centered around the well known column generation technique. Different practical applications of crew scheduling are presented, and some of these applications are considered in detail in four included scientific papers. It is shown how these applications all fit into a generalisation of the set partitioning model. Each
of the four papers contribute a novel solution method for the specific application treated in the paper.

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Authors: Rasmussen, M. S. (Intern), Larsen, J. (Intern)
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Source-ID: 313727
Publication: Research › Ph.D. thesis – Annual report year: 2011

**A multilevel variable neighborhood search heuristic for a practical vehicle routing and driver scheduling problem**
The world's second largest producer of pork, Danish Crown, also provides a fresh meat supply logistics system within Denmark. This is used by the majority of supermarkets in Denmark. This article addresses an integrated vehicle routing and driver scheduling problem arising at Danish Crown in their fresh meat supply logistics system. The problem consists of a 1-week planning horizon, heterogeneous vehicles, and drivers with predefined work regulations. These regulations include, among other things, predefined workdays, fixed starting time, maximum weekly working duration, and a break rule. The objective is to minimize the total delivery cost that is a weighted sum of two kinds of delivery costs. A multilevel variable neighborhood search heuristic is proposed for the problem. In a preprocessing step, the problem size is reduced through an aggregation procedure. Thereafter, the aggregated weekly planning problem is decomposed into daily planning problems, each of which is solved by a variable neighborhood search. Finally, the solution of the aggregated problem is expanded to that of the original problem. The method is implemented and tested on real-life data consisting of up to 2,000 orders per week. Computational results show that the aggregation procedure and the decomposition strategy are very effective in solving this large scale problem, and our solutions are superior to the industrial solutions given the constraints considered in this work.

**General information**
State: Published
Organisations: Logistics & ITS, Department of Transport, Operations Research, Department of Management Engineering, Technical University of Denmark
Authors: Wen, M. (Intern), Krapper, E. (Ekstern), Larsen, J. (Intern), Stidsen, T. R. (Intern)
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BFI (2016): BFI-level 1
Scopus rating (2016): SJR 1.188 SNIP 1.093 CiteScore 1.22
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): SJR 0.927 SNIP 1.033 CiteScore 1.21
BFI (2014): BFI-level 2
Scopus rating (2014): SJR 0.955 SNIP 1.358 CiteScore 1.03
BFI (2013): BFI-level 2
An IP Framework for the Crew Pairing Problem Using Subsequence Generation

In this paper we consider an important problem for the airline industry. The widely studied crew pairing problem is typically formulated as a set partitioning problem and solved using the branch-and-price methodology. Here we develop a new integer programming framework, based on the concept of subsequence generation, for solving the set partitioning formulation. In subsequence generation one restricts the number of permitted subsequent flights, that a crew member can turn to after completing any particular flight. By restricting the number of subsequences, the number of pairings in the problem decreases. The aim is then to dynamically add attractive subsequences to the problem, thereby increasing the number of possible pairings and improving the solution quality. Encouraging results are obtained on 19 real-life instances supplied by Air New Zealand and show that the described methodology is a viable alternative to column generation.
Improved exact method for the double TSP with multiple stacks

The Double TSP with Multiple Stacks is a logistics problem where one must, using a container, transport a given number of orders from a set of pickup customers to a set of delivery customers at minimum cost. Each order corresponds to the movement of one pallet, all pickups must be completed before the first delivery, and the container cannot be repacked once packed. In this paper we improve the previously proposed exact method of Lusby et al. (Int Trans Oper Res 17 (2010), 637–652) through an additional preprocessing technique that uses the longest common subsequence between the respective pickup and delivery problems. The results suggest an impressive improvement, and we report, for the first time, optimal solutions to several unsolved instances from the literature containing 18 customers. Instances with 28 customers are also shown to be solvable within a few percent of optimality. © 2011 Wiley Periodicals, Inc. NETWORKS, Vol. 58(4), 290–300 2011

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BFI (2016): BFI-level 1
Scopus rating (2016): SJR 1.188 SNIP 1.093 CiteScore 1.22
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): SJR 0.927 SNIP 1.033 CiteScore 1.21
BFI (2014): BFI-level 2
Scopus rating (2014): SJR 0.955 SNIP 1.358 CiteScore 1.03
BFI (2013): BFI-level 2
Scopus rating (2013): SJR 1.158 SNIP 1.282 CiteScore 1.24
ISI indexed (2013): ISI indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): SJR 0.801 SNIP 1.017 CiteScore 0.85
ISI indexed (2012): ISI indexed yes
BFI (2011): BFI-level 2
Scopus rating (2011): SJR 0.969 SNIP 1.32 CiteScore 1.18
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 2
Scopus rating (2010): SJR 1.453 SNIP 1.237
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 2
Models for the discrete berth allocation problem: A computational comparison

In this paper we consider the problem of allocating arriving ships to discrete berth locations at container terminals. This problem is recognized as one of the most important processes for any container terminal. We review and describe three main models of the discrete dynamic berth allocation problem, improve the performance of one model, and, through extensive numerical tests, compare all models from a computational perspective. The results indicate that a generalized set-partitioning model outperforms all other existing models.

General information

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Organisations: Logistics & ITS, Department of Transport, Operations Research, Department of Management Engineering, Technical University of Denmark
Authors: Buhrkal, K. F. (Intern), Zuglian, S. (Ekstern), Røpke, S. (Intern), Larsen, J. (Intern), Lusby, R. M. (Intern)
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Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): CiteScore 3.51
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): CiteScore 3.59
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): CiteScore 3.64
Railway Track Allocation: Models and Methods

Efficiently coordinating the movement of trains on a railway network is a central part of the planning process for a railway company. This paper reviews models and methods that have been proposed in the literature to assist planners in finding train routes. Since the problem of routing trains on a railway network entails allocating the track capacity of the network (or part thereof) over time in a conflict-free manner, all studies that model railway track allocation in some capacity are considered relevant. We hence survey work on the train timetabling, train dispatching, train platforming, and train routing problems, group them by railway network type, and discuss track allocation from a strategic, tactical, and operational level.

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Organisations: Operations Research, Department of Management Engineering, University of Auckland
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Web of Science (2017): Indexed Yes
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Scopus rating (2016): CiteScore 2.23 SJR 1.539 SNIP 1.645
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 1.478 SNIP 1.364 CiteScore 1.92
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 1.443 SNIP 1.483 CiteScore 1.72
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 2.015 SNIP 1.888 CiteScore 2.22
ISI indexed (2013): ISI indexed yes
Routing trains through railway junctions: A new set-packing approach

The problem of routing trains through railway junctions is an integral part of railway operations. Large junctions are highly interconnected networks of track where multiple railway lines merge, intersect, and split. The number of possible routings makes this a very complicated problem. We show how the problem can be formulated as a set-packing model with a resource-based constraint system. We prove that this formulation is tighter than the conventional node-packing model, and develop a branch-and-price algorithm that exploits the structure of the set-packing model. A discussion of the variable generation phase, as well as a pricing routine in which these variables are represented by tree structures, is also described. Computational experiments on 25 random timetables show this to be an efficient approach. © 2011 INFORMS.

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Organisations: Operations Research, Department of Management Engineering, University of Auckland
Authors: Lusby, R. M. (Intern), Larsen, J. (Intern), Ryan, D. (Ekstern), Ehrgott, M. (Ekstern)
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Journal: Transportation Science
Subsequence Generation for the Airline Crew Pairing Problem

Good and fast solutions to the airline crew pairing problem are highly interesting for the airline industry, as crew costs are the biggest expenditure after fuel for an airline. The crew pairing problem is typically modelled as a set partitioning problem and solved by column generation. However, the extremely large number of possible columns naturally has an impact on the solution time. In the solution method of this work we severely limit the number of allowed subsequent ights, i.e. the subsequences, thereby significantly decreasing the number of possible columns. Set partitioning problems with limited subsequence counts are known to be easier to solve, resulting in a decrease in solution time. The problem though, is that a small number of deep subsequences might be needed for an optimal or near-optimal solution and these might not have been included by the subsequence limitation. Therefore, we try to identify or generate such subsequences that potentially can improve the solution value. We benchmark the subsequence generation approach against a classical column generation approach on real-life test instances. We consider the LP relaxation and compare the quality and the integrality of the solutions. The LP solutions from the subsequence generation approach are less fractional, but it comes at the cost of a worse solution quality. The approach in the present paper is novel. To our knowledge generation of subsequences have not been described and tested previously in the literature.

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Electronic versions: rap9(2).11.pdf
Links:
Source: orbit
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Publication: Research › Report – Annual report year: 2011

The vehicle routing problem with time windows and temporal dependencies
In this article, we formulate the vehicle routing problem with time windows and temporal dependencies. The problem is an extension of the well studied vehicle routing problem with time windows. In addition to the usual constraints, a scheduled time of one visit may restrain the scheduling options of other visits. Special cases of temporal dependencies are synchronization and precedence constraints. Two compact formulations of the problem are introduced and the Dantzig–Wolfe decompositions of these formulations are presented to allow for a column generation-based solution approach. Temporal dependencies are modeled by generalized precedence constraints. Four different master problem formulations are proposed and it is shown that the formulations can be ranked according to the tightness with which they describe the solution space. A tailored time window branching is used to enforce feasibility on the relaxed master problems. Finally, a computational study is performed to quantitatively reveal strengths and weaknesses of the proposed formulations. It is concluded that, depending on the problem at hand, the best performance is achieved either by relaxing the generalized precedence constraints in the master problem, or by using a time-indexed model, where generalized precedence constraints are added as cuts when they become severely violated. © 2011 Wiley Periodicals, Inc.

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Journal: Networks
Rostering and Task Scheduling: Applications in Manpower Planning

In a modern society, manpower can be both a scarce and an expensive resource. Skilled personnel is usually in high demand and accounts for a significant part of total expenses in many companies. When the work is divided into shifts, a roster is compiled to allocate these to the employees. The rostercing process is non-trivial and especially when service is required around the clock, rostering may involve considerable effort from a designated planner. Therefore, in order to
minimize costs and overstaffing, to maximize the utilization of available staff, and to ensure a high level of satisfaction among the employees, sophisticated scheduling methods are required. When approaching the day of operation, the detail level of the planning becomes finer. With a given allocation of shifts to employees, the focus is turned to tasks scheduling within those shifts. The objective is to assign as much work as possible to the available staff, while respecting various requirements and rules and while including possible transportation time between tasks. This thesis presents a number of industrial applications in rostering and task scheduling. The applications exist within various contexts in health care, the aviation industry, transportation, and production. The focus regarding rostering is both on a generalized rostering problem, which captures most realistic settings, and also on a more specific case, where particular issues and extensions are examined. In task scheduling, the focus is restricted to scheduling problems with temporal dependencies between tasks. However, these problems appear in various contexts and with different properties. A group of the problems considered are related to vehicle routing problems, where transportation and time windows are important factors that must be accounted for. Mathematical and logic-based models are presented for the problems considered. Novel components are added to existing models and the modeling decisions are justified. In one case, the model is solved by a simple, but efficient greedy construction heuristic. In the remaining cases, column generation is applied. Column generation is an iterative exact solution method based on the theory of linear programming and is capable of providing provably optimal solutions. In some of the applications, the approach is modified to provide feasible solutions of high-quality in less time. The exceptional solution quality of column generation is maintained, but the certificate of optimality is compromised.

The contribution of this thesis is partly in the introduction, extension, and refinement of mathematical models for practical planning problems. Further, the contribution is in the proposed solution methods, which produce applicable and superior results to a range of realistic manpower planning problems. The contributions are presented in six scientific papers, which are compiled in the thesis. These include the development of a versatile approach to generalized rostering, building on an idea of compile-time customization. Several extensions of practical rostering problems are presented. For task scheduling, a general modeling of temporal dependencies is introduced and included in the methodology of column generation. The approach is applied to several practical problems with promising results. Lastly, a novel approach to crane scheduling with superior results is presented.

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set partitioning problem, task scheduling, column generation, manpower planning, integer programming, crew scheduling, crane scheduling, rostering, optimization, branch-and-price, vehicle routing, dynamic programming

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Rich Vehicle Routing Problems and Applications
The Vehicle Routing Problem (VRP) is one of the most important and challenging optimization problems in the field of Operations Research. It was introduced by Dantzig and Ramser (1959) and defined as the problem of designing the optimal set of routes for a fleet of vehicles in order to serve a given set of customers. The VRP is a computationally hard combinatorial problem and has been intensively studied by numerous researchers in the last fifty years. Due to the significant economic benefit that can be achieved by optimizing the routing problems in practice, more and more attention has been given to various extensions of the VRP that arise in real life. These extensions are often called Rich Vehicle Routing Problems (RVRPs). In contrast to the research of classical VRP that focuses on the idealized models with unrealistic assumptions, the research of RVRPs considers those complicated constraints encountered in the real-life planning and provides solutions that are executable in practice. In this thesis, we investigated the models and algorithms of three practical vehicle routing problems. Each of them involves special practical issues that are only considered in very few papers. Our study of these problems was motivated by our cooperation with industrial companies, particularly Transvision A/S and its client distributors, and Danish Crown. The models and methods proposed in the thesis are general and can be applied to practical routing problems arising in many other distribution companies as well. We first consider a vehicle routing problem with cross-docking options, in which products are picked up from suppliers by vehicles, consolidated at the depot and immediately delivered to customers by the same set of vehicles. It is more complex than the
traditional vehicle routing problems in the sense that consolidation decisions have to be made at the depot and these
decisions interact with the planning of pickup and delivery routes. We presented a mathematical model and proposed a
Tabu Search based heuristic to solve it. It is shown that the approach can produce near-optimal solutions within very short
computational time on real-life data involving up to 200 pairs of suppliers and customers. The second problem we consider
is a dynamic vehicle routing problem with multiple objectives over a planning horizon that consists of multiple periods. In
this problem, customer orders are revealed incrementally over the planning horizon. The delivery plan must be made and
executed in every period without knowing the future orders. We modeled the problem as a mixed integer linear program
and solved it by means of a three-phase heuristic that works over a rolling planning horizon. The method improves the
company’s solution in terms of all the objectives, including the travel time, customer waiting and daily workload balances,
under the given constraints considered in the work. Finally, we address an integrated vehicle routing and driver scheduling
problem, in which a large number of practical constraints are considered, such as the multi-period horizon, the time
windows for the delivery, the heterogeneous vehicles, the drivers’ predefined working regulations, the driving rule etc. The
problem is formulated as a mixed integer linear program and treated by a multilevel variable neighborhood search
algorithm. The method is implemented and tested on real-life data involving up to 2000 orders. It is shown that the method
is able to provide solutions of good quality within reasonable running time.

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An Exact Method for the Double TSP with Multiple Stacks
The double travelling salesman problem with multiple stacks (DTSPMS) is a pickup and delivery problem in which all
pickups must be completed before any deliveries can be made. The problem originates from a real-life application where a
40 foot container (configured as 3 columns of 11 rows) is used to transport up to 33 pallets from a set of pickup customers
to a set of delivery customers. The pickups and deliveries are performed in two separate trips, where each trip starts and
ends at a depot and visits a number of customers. The aim of the problem is to produce a stacking plan for the pallets that
minimizes the total transportation cost (ignoring the cost of transporting the container between the depots of the two trips)
given that the container cannot be repacked at any stage. In this paper we present an exact solution method based on
matching k-best TSP solutions for each of the separate pickup and delivery TSP problems and show that previously
unsolved instances can be solved within seconds using this approach.

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An Integrated Approach to the Ground Crew Rostering Problem with Work Patterns

This paper addresses the Ground Crew Rostering Problem with Work Patterns, an important manpower planning problem arising in the ground operations of airline companies. We present a cutting stock based integer programming formulation of the problem and describe a powerful decomposition approach, which utilizes column generation and variable fixing, to construct efficient rosters for a six month time horizon. The time horizon is divided into smaller blocks, where overlaps between the blocks ensure continuity. The proposed methodology is able to circumvent one step of the conventional roster construction process by generating rosters directly based on the estimated workload. We demonstrate that this approach has the additional advantage of being able to easily incorporate robustness in the roster. Computational results on real-life instances confirm the efficiency of the approach.

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Disruption Management - Foreword

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Disruption management in the airline industry—Concepts, models and methods

This paper provides a thorough review of the current state-of-the-art within airline disruption management of resources, including aircraft, crew, passenger and integrated recovery. An overview of model formulations of the aircraft and crew scheduling problems is presented in order to emphasize similarities between solution approaches applied to the planning and recovery problems. A brief overview of research within schedule robustness in airline scheduling is included in the review, since this proactive measure is a natural complement to disruption management.

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Solving the Airline Crew Pairing Problem using Subsequence Generation

Good and fast solutions to the airline crew pairing problem are highly interesting for the airline industry, as crew costs are the biggest expenditure after fuel for an airline. The crew pairing problem is typically modelled as a set partitioning problem and solved by column generation. However, the extremely large number of possible columns naturally has an impact on the solution time. In this work in progress we severely limit the number of allowed subsequent flights, i.e. the subsequences, thereby significantly decreasing the number of possible columns. Set partitioning problems with limited subsequence counts are known to be easier to solve, resulting in a decrease in solution time. The problem though, is that a small number of deep subsequences might be needed for an optimal or near-optimal solution and these might not have been included by the subsequence limitation. Therefore, we try to identify or generate such subsequences that potentially can improve the solution value.

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The dynamic multi-period vehicle routing problem

This paper considers the Dynamic Multi-Period Vehicle Routing Problem which deals with the distribution of orders from a depot to a set of customers over a multi-period time horizon. Customer orders and their feasible service periods are dynamically revealed over time. The objectives are to minimize total travel costs and customer waiting, and to balance the daily workload over the planning horizon. This problem originates from a large distributor operating in Sweden. It is modeled as a mixed integer linear program, and solved by means of a three-phase heuristic that works over a rolling planning horizon. The multi-objective aspect of the problem is handled through a scalar technique approach. Computational results show that the proposed approach can yield high quality solutions within reasonable running times.
The Home Care Crew Scheduling Problem: Preference-Based Visit Clustering and Temporal Dependencies

In the Home Care Crew Scheduling Problem a staff of caretakers has to be assigned a number of visits to patients' homes, such that the overall service level is maximised. The problem is a generalisation of the vehicle routing problem with time windows. Required travel time between visits and time windows of the visits must be respected. The challenge when assigning visits to caretakers lies in the existence of soft preference constraints and in temporal dependencies between the start times of visits. We model the problem as a set partitioning problem with side constraints and develop an exact branch-and-price solution algorithm, as this method has previously given solid results for classical vehicle routing.
problems. Temporal dependencies are modelled as generalised precedence constraints and enforced through the branching. We introduce a novel visit clustering approach based on the soft preference constraints. The algorithm is tested both on real-life problem instances and on generated test instances inspired by realistic settings. The use of the specialised branching scheme on real-life problems is novel. The visit clustering decreases run times significantly, and only gives a loss of quality for few instances. Furthermore, the visit clustering allows us to find solutions to larger problem instances, which cannot be solved to optimality.

Agent Based Individual Traffic Guidance
This thesis investigates the possibilities in applying Operations Research (OR) to autonomous vehicular traffic. The explicit difference to most other research today is that we presume that an agent is present in every vehicle - hence Agent Based Individual Traffic guidance (ABIT). The next evolutionary step for the in-vehicle route planners is the introduction of two-way communication. We presume that the agent is capable of exactly this. Based on this presumption we discuss the possibilities and define a taxonomy and use this to discuss the ABIT system. Based on a set of scenarios we conclude that the system can be divided into two separate constituents. The immediate dispersion, which is used for small areas and quick response, and the individual alleviation, which considers the longer distance decision support. Both of these require intrinsicate models and cost functions which at the beginning of the project were not previously considered. We define a special inseparable cost function and develop a solution complex capable of using this cost function. In relation to calibration and estimation of statistical models used for dynamic route guidance we worked with generating random number sequences. During this work we made significant findings related to random numbers.
Decision Support for the Rolling Stock Dispatcher

Real-time recovery is receiving a fast growing interest in an increasingly competitive railway operation market. This thesis considers the area of rolling stock dispatching which is one of the typical real-time railway dispatching problems. All work of the thesis is based on the network and planning processes of the railway operator DSB S-tog a/s. In the thesis the problems existing in the railway planning process from the strategic to real-time level are briefly sketched. Network planning, line planning, timetabling, crew and rolling stock planning is outlined and relevant references are given. Specifically the thesis references the operation research studies based on the railway operation of DSB S-tog a/s. Subsequently the process of dispatching is outlined with a specific emphasis on rolling stock. The rolling stock recovery problem is the problem of assigning train units to train departures in a disrupted rolling stock schedule so that operation returns quickly to the originally planned schedule. Different network structures and mathematical formulations for the problem are discussed. Based on prior work on network structures a decomposed approach for the rolling stock recovery problem is put forward. The main contributions of the thesis are contained in four papers included as appendices. The papers deal with respectively an analysis of robustness in timetables, the mathematical model behind a decision support tool for reinsertion of a train line, a survey on the dispatching problems of passenger railway transportation and the decomposed solution process of the rolling stock recovery problem. The paper on the robustness analysis has been accepted for submission in the International Journal of Operations Research. Two of the papers have been submitted to journals and are being reviewed. The last paper will be submitted. Furthermore, the work of the two papers on the robustness analysis respectively the reinsertion model have formed the basis of practical projects in DSB S-tog. The applicability of the decomposed process will be further investigated in the future.

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A multi-level variable neighborhood search heuristic for a practical vehicle routing and driver scheduling problem

This paper addresses an integrated vehicle routing and driver scheduling problem arising at the largest fresh meat producer in Denmark. The problem consists of a one-week planning horizon, heterogeneous vehicles, and drivers with predefined work regulations. These regulations include, among other things, predefined workdays, fixed starting time, maximum weekly working duration, break rule. The objective is to minimize the total delivery cost. The real-life case study is first introduced and modelled as a mixed integer linear program. A multilevel variable neighborhood search heuristic is then proposed for the problem. At the first level, the problem size is reduced through an aggregation procedure. At the second level, the aggregated weekly planning problem is decomposed into daily planning problems, each of which is solved by a variable neighborhood search. At the last level, the solution of the aggregated problem is expanded to that of the original problem. The method is implemented and tested on real-life data consisting of up to 2000 orders per week. Computational results show that the aggregation procedure and the decomposition strategy are very effective in solving this large scale problem, and our solutions are superior to the industrial solutions given the constraints considered in this work.

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An Exact Method for the Double TSP with Multiple Stacks

The double travelling salesman problem with multiple stacks (DTSPMS) is a pickup and delivery problem in which all pickups must be completed before any deliveries can be made. The problem originates from a real-life application where a 40 foot container (configured as 3 columns of 11 rows) is used to transport up to 33 pallets from a set of pickup customers to a set of delivery customers. The pickups and deliveries are performed in two separate trips, where each trip starts and ends at a depot and visits a number of customers. The aim of the problem is to produce a stacking plan for the pallets that minimizes the total transportation cost (ignoring the cost of transporting the container between the depots of the two trips) given that the container cannot be repacked at any stage. In this paper we present an exact solution method based on matching k-best TSP solutions for each of the separate pickup and delivery TSP problems and show that previously unsolved instances can be solved within seconds using this approach.

A Set Packing Inspired Method for Real-Time Junction Train Routing

Efficiently coordinating the often large number of interdependent, timetabled train movements on a railway junction, while satisfying a number of operational requirements, is one of the most important problems faced by a railway company. The most critical variant of the problem arises on a daily basis at major railway junctions where disruptions to rail traffic make the planned schedule/routing infeasible and rolling stock planners are forced to reschedule/re-route trains in order to recover feasibility. The dynamic nature of the problem means that good solutions must be obtained quickly. In this paper we describe a set packing inspired formulation of this problem and develop a branch-and-price based solution approach. A real life test instance arising in Germany and supplied by the major German railway company, Deutsche Bahn, indicates the efficiency of the proposed approach by confirming that practical problems can be solved to within a few percent of optimality in reasonable time.
Models for the Discrete Berth Allocation Problem: A Computational Comparison

In this paper we consider the problem of allocating arriving ships to discrete berth locations at container terminals. This problem is recognized as one of the most important processes for any container terminal. We review and describe the three main models of the discrete dynamic berth allocation problem, improve the performance of one model, and, through extensive numerical tests, compare all models from a computational perspective. The results indicate that a generalized setpartitioning model outperforms all other existing models.

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Railway Track Allocation: Models and Methods

Efficiently coordinating the movement of trains on a railway network is a central part of the planning process for a railway company. This paper reviews models and methods that have been proposed in the literature to assist planners in finding train routes. Since the problem of routing trains on a railway network entails allocating the track capacity of the network (or part thereof) over time in a conflict-free manner, all studies that model railway track allocation in some capacity are considered relevant. We hence survey work on the train timetabling, train dispatching, train platforming, and train routing problems, group them by railway network type, and discuss track allocation from a strategic, tactical, and operational level.
Solving the Airline Crew Pairing Problem using Subsequence Generation

Good and fast solutions to the airline crew pairing problem are highly interesting for the airline industry, as crew costs are the biggest expenditure after fuel for an airline. The crew pairing problem is typically modelled as a set partitioning problem and solved by column generation. However, the extremely large number of possible columns naturally has an impact on the solution time. In this work in progress we severely limit the number of allowed subsequent flights, i.e. the subsequences, thereby significantly decreasing the number of possible columns. Set partitioning problems with limited subsequence counts are known to be easier to solve, resulting in a decrease in solution time. The problem though, is that a small number of deep subsequences might be needed for an optimal or near-optimal solution and these might not have been included by the subsequence limitation. Therefore, we try to identify or generate such subsequences that potentially can improve the solution value.

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The Dynamic Multi-Period Vehicle Routing Problem

This paper considers the Dynamic Multi-Period Vehicle Routing Problem which deals with the distribution of orders from a depot to a set of customers over a multi-period time horizon. Customer orders and their feasible service periods are dynamically revealed over time. The objectives are to minimize total travel costs and customer waiting, and to balance the daily workload over the planning horizon. This problem originates from a large distributor operating in Sweden. It is modeled as a mixed integer linear program, and solved by means of a three-phase heuristic that works over a rolling planning horizon. The multi-objective aspect of the problem is handled through a scalar technique approach. Computational results show that our solutions improve upon those of the Swedish distributor.

The Vehicle Routing Problem with Time Windows and Temporal Dependencies

This paper considers the Vehicle Routing Problem with Time Windows and Temporal Dependencies which deals with the distribution of orders from a depot to a set of customers over a multi-period time horizon. Customer orders and their feasible service periods are dynamically revealed over time. The objectives are to minimize total travel costs and customer waiting, and to balance the daily workload over the planning horizon. This problem originates from a large distributor operating in Sweden. It is modeled as a mixed integer linear program, and solved by means of a three-phase heuristic that works over a rolling planning horizon. The multi-objective aspect of the problem is handled through a scalar technique approach. Computational results show that our solutions improve upon those of the Swedish distributor.
The Vehicle Routing Problem with Time Windows and Temporal Dependencies

The vehicle routing problem with time windows and temporal dependencies (VRPTWTD) is an extension of the vehicle routing problem with time windows (VRPTW). Given is a fixed set of customers with individual demands and with time windows specifying when each customer accepts service. The objective is to find routes for a number of vehicles, all starting and ending at a central depot in such a way that the total distance is minimized. The extension that we present here is concerned with temporal dependencies between customers. A temporal dependency which is often encountered in practical instances and that has received the most attention in the literature, is the rather strict requirement of synchronization between two visits. Synchronization on visits is also used to model rendezvous between vehicles. Other, less restrictive, dependencies are constraints on minimum overlap between visits and limits on minimum or maximum gaps between visits. There is a vast amount of literature on VRPTW and its variants. VRPTW is known to be NP-hard, nevertheless exact solution of the problem has received a lot of attention. The most successful approach is based on a Dantzig-Wolfe decomposition of the mathematical model using column generation in a branch-and-cut-and-price framework. The motivation behind this work on the VRPTWTD is its many practical applications. With the inclusion of temporal dependencies in the model, we are able to describe numerous concrete problems. Practical applications include the fleet assignment and routing problem with synchronization constraints. The problem has been solved by column generation. The synchronized vehicle dispatching problem (SVDP), which is a dynamic vehicle routing problem with synchronization between vehicles. Constraint programming and local search are applied to arrive at high-quality feasible solutions. A problem from the Port of Singapore, where technicians are allocated to service jobs has previously been studied. For each job, a certain combination of technicians with individual skills is needed. The technicians must be present at the same time, and hence the schedule for each technician must respect a number of synchronization constraints with other schedules. The problem is solved using metaheuristics. Another application with synchronization between visits is in ground handling at airports. Teams drive around at the airport and are assigned tasks on the parked aircrafts. A recent paper describes this setup and present exact solutions to the instances considered. Another work considers ground handling with synchronization constraints as well, and present computational results for a tailored heuristic applied to data instances from an in-flight caterer in Malaysia. An application of vehicle routing with synchronization constraints is done with a branch-and-price algorithm applied to a realistic home care routing problem and yields promising results. The generalization of synchronization to other temporal dependencies has been described for a few applications. A paper presents a workforce scheduling software from a practical perspective. In the problem described, both synchronization and various other sequencing constraints occur. Another application describes a problem in school bus routing. Busses must wait for each other at various intermediate stops and hence precedence relations are introduced for such stops. The problem is referred to as the vehicle routing problem with coupled time windows. A work describes an application in blood collection from satellite locations for a central blood bank. Multiple visits at each location have to be scheduled with a certain slack between them. They refer to the vehicle problem as having interdependent time windows. Temporal dependencies have been modeled for a home care routing problem in a mixed integer programming model (MIP) which was solved with a standard MIP solver. An application with general temporal dependencies is also found in machine scheduling. Column generation is used to solve the problem. The pricing problem is primarily solved heuristically by local search and occasionally to optimality using a standard solver on an integer programming formulation of the pricing problem. Two compact formulations of the problem are introduced and the Dantzig-Wolfe decompositions of these formulations are presented to allow for a column-generation-based solution approach. Temporal dependencies are modeled by generalized precedence constraints. A total of four different master problem formulations are proposed and it is shown that the formulations can be ranked according to the tightness with which they describe the solution space. A tailored time window branching is used to enforce feasibility on the relaxed master problems. The contribution of this work is the generalization of synchronization to any temporal dependency that can be described by generalized precedence constraints, as well as the inclusion of this in a branch-and-price context. We prove that the generalization is as strong as the formerly introduced model with synchronization. The use of the time-indexed model in the column generation is novel as well. Finally, we introduce a new set of context-free benchmark instances which enables a thorough quantitative analysis and which we hope will facilitate future research in this area. The analysis shows that, even though the time-indexed model has some nice properties, it also retains its major drawback, namely the number of constraints. As a consequence, a hybrid method is implemented, where only a limited number of the violated cuts are added. This approach keeps most of the nice features of the time-indexed model, while at the same time lowering the solution time to the same level as the solution time of the relaxed model. In fact the hybrid method is only slower than the relaxed model in a small number of instances. The model presented in this paper is general and is therefore applicable to various practical problems. Future work could be adaption to real world problems. Another very interesting direction for future research could be to include additional cuts. Using the time-indexed formulation, we were able to solve many instances already in the root node of the branch-and-bound tree, and this number could be increased by introducing additional cuts. The performance of the time-indexed model was clearly better than the relaxed model for the instances where the optimal solution was obtained in the root node.
Vehicle routing with cross-docking

Over the past decade, cross-docking has emerged as an important material handling technology in transportation. A variation of the well-known Vehicle Routing Problem (VRP), the VRP with Cross-Docking (VRPCD) arises in a number of logistics planning contexts. This paper addresses the VRPCD, where a set of homogeneous vehicles are used to transport orders from the suppliers to the corresponding customers via a cross-dock. The orders can be consolidated at the cross-dock but cannot be stored for very long because the cross-dock does not have long-term inventory-holding capabilities. The objective of the VRPCD is to minimize the total travel time while respecting time window constraints at the nodes and a time horizon for the whole transportation operation. In this paper, a mixed integer programming formulation for the VRPCD is proposed. A tabu search heuristic is embedded within an adaptive memory procedure to solve the problem. The proposed algorithm is implemented and tested on data sets provided by the Danish consultancy Transvision, and involving up to 200 pairs of nodes. Experimental results show that this algorithm can produce high-quality solutions (less than 5% away from optimal solution values) within very short computational time.
Green Wave Traffic Optimization - A Survey
The objective of this survey is to cover the research in the area of adaptive traffic control with emphasis on the applied optimization methods. The problem of optimizing traffic signals can be viewed in various ways, depending on political, economic and ecological goals. The survey highlights some important conflicts, which support the notion that traffic signal optimization is a multi-objective problem, and relates this to the most common measures of effectiveness. A distinction can be made between classical systems, which operate with a common cycle time, and the more flexible, phase-based, approach, which is shown to be more suitable for adaptive traffic control. To support this claim three adaptive systems, which use alternatives to the classical optimization procedures, are described in detail.

General information
State: Published
Organisations: Operations Research, Department of Informatics and Mathematical Modeling, Logistics & ITS, Department of Transport
Authors: Warberg, A. (Ekstern), Larsen, J. (Intern), Jørgensen, R. M. (Intern)
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The Home Care Crew Scheduling Problem

General information
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Airline Disruption Management - Perspectives, Experiences and Outlook

Over the past decade, airlines have become more concerned with developing an optimal flight schedule, with very little slack left to accommodate for any form of variation from the optimal solution. During operation the planned schedules often have to be revised due to disruptions caused by for example severe weather, technical problems and crew sickness. Thus, the field of Airline Disruption Management has emerged within the past few years. The increased focus on cutting cost at the major airlines has intensified the interest in the development of new and cost efficient methods to handle airline disruptions. The purpose of this paper is twofold. In the first part it offers an introduction to airline disruption management and provides the readers with a description of the planning processes and delivers a detailed overview of the numerous aspects of airline disruption management. In the second part we report on experiences from a large research and development project on airline disruption management. Within the project the first prototype of a multiple resource decision support system at the operations control center in a major airline, has been implemented.

General information
State: Published
Organisations: Department of Informatics and Mathematical Modeling, Logistics & ITS, Department of Transport, Operations Research, British Airways, Carmen System A.B.
Authors: Kohl, N. (Intern), Larsen, A. (Intern), Larsen, J. (Intern), Ross, A. (Ekstern), Tiourine, S. (Ekstern)
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BFI (2018): BFI-level 1
A Hub Location Problem with Fully Interconnected Backbone and Access Networks

This paper considers the design of two-layered fully interconnected networks. A two-layered network consists of clusters of nodes, each defining an access network and a backbone network. We consider the integrated problem of determining the access networks and the backbone network simultaneously. A mathematical formulation is presented, but as the linear programming relaxation of the mathematical formulation is weak, a formulation based on the set partitioning model and column generation approach is also developed. The column generation subproblems are solved by solving a series of quadratic knapsack problems. We obtain superior bounds using the column generation approach than with the linear programming relaxation. The column generation method is therefore developed into an exact approach using the Branch-and-Price framework. With this approach we are able to solve problems consisting of up to 25 nodes in reasonable time. Given the difficulty of the problem, the results are encouraging.
Solving the Dial-a-Ride Problem using Genetic Algorithms

In the Dial-a-Ride problem (DARP), customers request transportation from an operator. A request consists of a specified pickup location and destination location along with a desired departure or arrival time and capacity demand. The aim of DARP is to minimize transportation cost while satisfying customer service level constraints (Quality of Service). In this paper, we present a genetic algorithm (GA) for solving the DARP. The algorithm is based on the classical cluster-first, route-second approach, where it alternates between assigning customers to vehicles using a GA and solving independent routing problems for the vehicles using a routing heuristic. The algorithm is implemented in Java and tested on publicly available data sets. The new solution method has achieved solutions comparable with the current state-of-the-art methods.
On the vehicle routing problem with time windows

The vehicle routing problem with time windows is concerned with the optimal routing of a fleet of vehicles between a depot and a number of customers that must be visited within a specified time interval, called a time window. The purpose of this thesis is to develop new and efficient solution techniques for solving the vehicle routing problem with time windows (VRPTW). The thesis consists of a section of introductory remarks and four independent papers.

The first paper ‘Formulations and exact approaches for the vehicle routing problem with time windows’ (Kallehauge, 2005, unpublished) is a review of the exact algorithms proposed in the last three decades for the solution of the vehicle routing problem with time windows. A detailed analysis of the formulations of the VRPTW is presented together with a review of the literature related to the different formulations. We present the two main lines of development in relation to the exact approaches for the VRPTW. One is concerned with the general decomposition approach and the solution to certain dual problems associated with the VRPTW. Another more recent direction is concerned with the analysis of the polyhedral structure of the VRPTW. We conclude by examining possible future lines of research in the area of the VRPTW.

In the second paper ‘Lagrangian duality applied to the vehicle routing problem with time windows’ (Kallehauge, Larsen, and Madsen, Computers & Operations Research, 33:1464-1487, 2006) we consider the Lagrangian relaxation of the constraint set requiring that each customer must be served by exactly one vehicle yielding a constrained shortest path subproblem. We present a stabilized cutting-plane algorithm within the framework of linear programming for solving the associated Lagrangian dual problem. This algorithm creates easier constrained shortest path subproblems because less negative cycles are introduced and it leads to faster multiplier convergence due to a stabilization of the dual variables. We have embedded the stabilized cutting-plane algorithm in a branch-and-bound search and introduce strong valid inequalities at the master problem level by Lagrangian relaxation. The result is a Lagrangian branch-and-cut-and-price (LBCP) algorithm for the VRPTW. Making use of this acceleration strategy at the master problem level gives a significant speed-up compared to algorithms in the literature based on traditional column generation. We have solved two test problems introduced in 2001 by Gehring and Homberger with 400 and 1000 customers respectively, which to date are the largest problems ever solved to optimality. We have implemented the LBCP algorithm using the ABACUS open-source framework for solving mixed-integer linear-programs by branch, cut, and price.

In the third paper ‘Path inequalities for the vehicle routing problem with time windows’ (Kallehauge, Boland, and Madsen, 2005, submitted) we introduce a new formulation of the VRPTW involving only binary variables associated with the arcs in the underlying digraph. The new formulation is based on a formulation of the asymmetric traveling salesman problem with time windows and has the advantage of avoiding additional variables and linking constraints. In the new formulation of the VRPTW time windows are modeled using path inequalities. The path inequalities eliminate time and capacity infeasible paths. We present a new class of strengthened path inequalities based on polyhedral results obtained in the context of the asymmetric traveling salesman problem with replenishment arcs. We study the VRPTW polytope and determine the
polytope dimension. We show that the lifted path inequalities are facet defining under certain assumptions. We also introduce precedence constraints in the context of the VRPTW. Computational experiments are performed with a branch-and-cut algorithm on the Solomon test problems with wide time windows. Based on results on 25-node problems the outcome is that the algorithm shows promising results compared to leading algorithms in the literature. In particular we report a solution to a previously unsolved 50-node Solomon test problem R208. The conclusion is therefore that the path formulation of the VRPTW is no longer the unchallenged winning strategy for solving the VRPTW.

The fourth and final paper 'Vehicle routing problem with time windows' (Kallehauge, Larsen, Madsen, and Solomon. In Desaulniers, Desrosiers, and Solomon, editors, Column generation, pages 67-98, Springer, New York, 2005) is a contribution to a book on column generation edited by G. Desaulniers, J. Desrosiers, and M. M. Solomon. The focus of the paper is on the VRPTW as one of the important applications of column generation in integer programming. We discuss the VRPTW in terms of its mathematical modeling, its structure and decomposition alternatives. We then present the master problem and the subproblem for the column generation approach, respectively. Next, we illustrate a branch-and-bound framework and address acceleration strategies used to increase the efficiency of branch-and-price methods. Then, we describe generalizations of the problem and report computational results for the classic Solomon test sets. Finally, we present our conclusions and discuss some open problems.

General information
State: Published
Organisations: Logistics & ITS, Department of Transport, Operations Research, Department of Informatics and Mathematical Modeling
Authors: Kallehauge, B. (Intern), Madsen, O. B. (Intern), Larsen, J. (Intern), Madsen, K. (Intern)
Number of pages: 115
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Publication: Research › Ph.D. thesis – Annual report year: 2006

Finding the best visualization of an ontology
An ontology is a classification model for a given domain. In information retrieval ontologies are used to perform broad searches. An ontology can be visualized as nodes and edges. Each node represents an element and each edge a relation between a parent and a child element. Working with an ontology becomes easier with a visual representation. An idea is to use the expressive power that a 3D representation to provide visualization for the user. In this paper we propose a new method for positioning the elements of the visualized concept lattice in the 3D world based on Operations Research (OR) methods. One method uses a discrete location model to create an initial solution and we propose heuristic methods to further improve the visual result. We evaluate the visual results according to our success criteria and the feedback from users. Running times of the heuristic indicate that an improved version should be feasible for on-line processing and what-if analysis of ontologies.

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Organisations: Operations Research, Department of Informatics and Mathematical Modeling
Authors: Fabritius, C. (Ekstern), Madsen, N. (Ekstern), Clausen, J. (Intern), Larsen, J. (Intern)
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BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 2
Web of Science (2017): Indexed Yes
BFI (2016): BFI-level 2
Scopus rating (2016): SJR 1.004 SNIP 1.052 CiteScore 1.59
Lagrangian duality applied to the vehicle routing problem with time windows

This paper considers the vehicle routing problem with time windows, where the service of each customer must start within a specified time interval. We consider the Lagrangian relaxation of the constraint set requiring that each customer must be served by exactly one vehicle yielding a constrained shortest path subproblem. We present a stabilized cutting-plane algorithm within the framework of linear programming for solving the associated Lagrangian dual problem. This algorithm creates easier constrained shortest path subproblems because less negative cycles are introduced and it leads to faster multiplier convergence due to a stabilization of the dual variables. We have embedded the stabilized cutting-plane algorithm in a branch-and-bound search and introduce strong valid inequalities at the master problem level by Lagrangian relaxation. The result is a Lagrangian branch-and-cut-and-price (LBCP) algorithm for the VRPTW. Making use of this acceleration strategy at the master problem level gives a significant speed-up compared to algorithms in the literature based on traditional column generation. We have solved two test problems introduced in 2001 by Gehring and Homberger with 400 and 1000 customers respectively, which to date are the largest problems ever solved to optimality. We have implemented the LBCP algorithm using the ABACUS open-source framework for solving mixed-integer linear-programs by branch, cut, and price.
Proceedings of the 1st Nordic Optimization Symposium - 10th Nordic MPS meeting, Copenhagen 2006

On behalf of the Technical University of Denmark, the Danish Operations Research Society and the Nordic Section of the Mathematical Programming Society we welcome you to Copenhagen and the 1st Nordic Optimization Symposium - the 10th meeting of the Nordic MPS. The meetings of the Nordic MPS have evolved to be more than just a meeting on Mathematical Programming. They are a forum for discussing a wide range of related areas and practical cases. In the organizing committee we wanted the name of the meeting to reflect this. We have therefore in agreement with the board of the Nordic MPS suggested to add a new title, that reflects the much broader field that is our playground at these meetings. Still the odd trustworthy title “Meeting of the Nordic MPS” has been maintained to demonstrate the origin of the symposium. It is our hope that future Nordic MPS meetings will carry on using this “double name”. The program includes 2 plenary lectures by Leo Kroon and Arne Drud and more than 50 contributed presentations. The symposium has this time expanded beyond our Nordic boundaries with participants from eg. the Netherlands, Italy and New Zealand. As a consequence the original 2 parallel streams we had in mind have extended to 3 throughout the symposium. It is our firm belief that this symposium will - like all the previous Nordic MPS meetings - be a fruitfull ground for collaboration and networking and thereby further tighten the ties between the Nordic countries in relation to optimization, Operations Research and Mathematical Programming. Finally we would like to thank our sponsors and supporter for their contributions. It has among other things made it possible to give free registration to a number of researchers from the Baltic countries and Ph.D. students in general. We wish you all an enjoyable 1st Nordic Optimization Symposium (10th Nordic MPS meeting) in Copenhagen.

General information
State: Published
Organisations: Operations Research, Department of Informatics and Mathematical Modeling, Department of Transport, Logistics & ITS
Authors: Clausen, J. (Intern), Jørgensen, R. M. (Intern), Kohl, N. (Intern), Larsen, J. (Intern), Madsen, O. B. (Intern)
Publication date: 2006

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Original language: English
Main Research Area: Technical/natural sciences
Recent Advances in the Vehicle Routing Problem with Time Windows

General information
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Organisations: Logistics & ITS, Department of Transport, Operations Research, Department of Informatics and Mathematical Modeling
Authors: Kallehauge, B. (Intern), Larsen, J. (Intern), Madsen, O. B. (Intern), Solomon, M. M. (Ekstern)
Number of pages: 4
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Robustness and Recovery in Train Scheduling - a simulation study from DSB S-tog a/s
This paper presents a simulation model to study the robustness of timetables of DSB S-tog a/s, the city rail of Copenhagen. Dealing with rush hour scenarios only, the simulation model investigates the effects of disturbances on the S-tog network. Several timetables are analyzed with respect to robustness. Some of these are used in operation and some are generated for the purpose of investigating timetables with specific alternative characteristics.

General information
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Organisations: Operations Research, Department of Informatics and Mathematical Modeling
Authors: Hofman, M. A. (Ekstern), Madsen, L. (Ekstern), Groth, J. J. (Intern), Clausen, J. (Intern), Larsen, J. (Intern)
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Routing Trains Through Railway Junctions: A New Set Packing Approach

The problem of routing trains through railway junctions is an integral part of railway operations. Large junctions are highly interconnected networks of track where multiple railway lines meet, intersect, and split. The number of possible routings makes this a very complicated problem. Here we show how the problem can be formulated as a set packing model. To exploit the structure of the problem we present a solution procedure which entails solving the dual of this formulation through the dynamic addition of violated cuts (primal variables). A discussion of the variable (train path) generation phase, as well as an efficient pricing routine in which these variables are represented by tree structures is also included. We illustrate the proposed methodology on an example junction with encouraging results. The decision support system currently being developed will enable planners to solve strategic, tactical, and operational level variants of the problem.

General information
State: Published
Organisations: Department of Informatics and Mathematical Modeling, Operations Research
Authors: Lusby, R. (Intern), Larsen, J. (Intern), Ryan, D. (Intern), Ehrgott, M. (Ekstern)
Publication date: 2006

An exact algorithm for Aircraft Landing Problem

General information
State: Published
Organisations: Operations Research, Department of Informatics and Mathematical Modeling
Authors: Wen, M. (Intern), Larsen, J. (Intern), Clausen, J. (Intern)
Publication date: 2005
Airline Disruption Management - Perspectives, Experiences and Outlook

Over the past decade, airlines have become more concerned with developing an optimal flight schedule, with very little slack left to accommodate for any form of variation from the optimal solution. During operation the planned schedules often have to be revised due to disruptions caused by for example severe weather, technical problems and crew sickness. Thus, the field of Airline Disruption Management has emerged within the past few years. The increased focus on cutting cost at the major airlines has intensified the interest in the development of new and cost-efficient methods to handle airline disruptions. The purpose of this paper is twofold. In the first part it offers an introduction to airline disruption management, provides the readers with a description of the planning processes and delivers a detailed overview of the numerous aspects of airline disruption management. In the second part we report on experiences from a large research and development project on airline disruption management. Within the project the first prototype of a multiple resource decision support system at the operations control center in a major airline, has been implemented.

General information
State: Published
Organisations: Department of Informatics and Mathematical Modeling, Department of Transport, Operations Research
Authors: Kohl, N. (Intern), Larsen, A. (Intern), Larsen, J. (Intern), Ross, A. (Ekstern), Tiourine, S. (Ekstern)
Number of pages: 36
Publication date: 2004

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Main Research Area: Technical/natural sciences
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Finding the best visualization of an ontology
An ontology is a classification model for a given domain. In information retrieval ontologies are used to perform broad searches. An ontology can be visualized as nodes and edges. Each node represents an element and each edge a relation between a parent and a child element. Working with an ontology becomes easier with a visual representation. An idea is to use the expressive power that a 3D representation to provide visualization for the user. In this paper we propose a new method for positioning the elements of the visualized concept lattice in the 3D world based on Operations Research (OR) methods. One method uses a discrete location model to create an initial solution and we propose heuristic methods to further improve the visual result. We evaluate the visual results according to our success criteria and the feedback from users. Running times of the heuristic indicate that an improved version should be feasible for on-line processing and what-if analysis of ontologies.

General information
State: Published
Organisations: Operations Research, Department of Informatics and Mathematical Modeling
Authors: Fabritius, C. V. (Ekstern), Madsen, N. L. (Ekstern), Clausen, J. (Intern), Larsen, J. (Intern)
Publication date: 2004

Refinements of the column generation process for the Vehicle Routing Problem with Time Windows
The Vehicle Routing Problem with Time Windows is a generalization of the well known capacity constrained Vehicle Routing Problem. A homogeneous fleet of vehicles has to service a set of the customers and fulfill their demands. The service of the customers can only start within a well-defined time interval denoted the time window. The objective is to determine routes for the vehicles that minimizes the accumulated cost (or distance) with respect to the above mentioned constraints. Currently the best approaches for determining optimal solutions are based on column generation and Branch-and-Bound, also known as Branch-and-Price. This paper presents two ideas for run-time improvements of the Branch-and-Price framework for the Vehicle Routing Problem with Time Windows. Both ideas reveal a significant potential for using run-time refinements when speeding up an exact approach without compromising optimality.

General information
State: Published
Organisations: Operations Research, Department of Informatics and Mathematical Modeling
Authors: Larsen, J. (Intern)
Pages: 326-341
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Main Research Area: Technical/natural sciences
Solving the Dial-a-Ride Problem using Genetic algorithms
In the Dial-a-Ride problem (DARP) customers send transportation requests to an operator. A request consists of a specified pickup location and destination location along with a desired departure or arrival time and demand. The aim of DARP is to minimize transportation cost while satisfying customer service level constraints (Quality of Service). In this paper we present a genetic algorithm for solving the DARP. The algorithm is based on the classical cluster-first route-second approach, where it alternates between assigning customers to vehicles using a genetic algorithm and solving independent routing problems for the vehicles using a routing heuristic. The algorithm is implemented in Java and tested on publicly available data sets.

General information
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Authors: Bergvinsdottir, K. B. (Ekstern), Larsen, J. (Intern), Jørgensen, R. M. (Intern)
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Publication: Research › Report – Annual report year: 2004

BORNHOLM '02 - Nordic Summer Course on Applied Optimization and Modelling

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State: Published
Organisations: Operations Research, Department of Informatics and Mathematical Modeling, Linköping University,
Norwegian University of Science and Technology
Authors: Larsen, J. (Intern), Rönqvist, M. (ed.) (Ekstern), Christiansen, M. (ed.) (Ekstern)
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Original language: English
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Publication: Research › Book – Annual report year: 2002
Disruption Management for an Airline - Rescheduling of aircraft
The Aircraft Recovery Problem (ARP) involves decisions concerning aircraft to flight assignments in situations where unforeseen events have disrupted the existing flight schedule, e.g. bad weather causing flight delays. The aircraft recovery problem aims to recover these flight schedules through a series of reassignments of aircraft to flights, delaying of flights and cancellations of flights. This article demonstrates an effective method to solve ARP. A heuristic is implemented, which is able to generate feasible revised flight schedules of a good quality in less than 10 seconds. This article is a product of the DESCARTES project, a project funded by the European Union between the Technical University of Denmark, British Airways and Carmen.

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Organisations: Operations Research, Department of Informatics and Mathematical Modeling, COOP
Authors: Larsen, J. (Intern), Løve, M. (Ekstern), Sørensen, K. R. (Ekstern), Clausen, J. (Intern)
Pages: 315-324
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Publisher: Springer
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Main Research Area: Technical/natural sciences
Conference: EvoWorkshops 2002, Kinsale, Ireland, 01/01/2002
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Introduktion til Operationsanalyse
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Organisations: Operations Research, Department of Informatics and Mathematical Modeling
Authors: Larsen, J. (Intern)
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Speeding up the solution process for the Vehicle Routing Problem with Time Windows using structural information
Two ideas for using structural information for solving the Vehicle Routing Problem with Time Windows (VRPTW) is presented. The VRPTW is a generalization of the well known capacity constrained Vehicle Routing Problem (VRP). Both techniques are based on solving the VRPTW using a Branch-and-Price approach. They reveal a huge potential for using structural information when speeding up an exact approach without compromising optimality.

General information
State: Published
Organisations: Operations Research, Department of Informatics and Mathematical Modeling
Authors: Larsen, J. (Intern)
Staff Scheduling within the Retail Business in Denmark

General information
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Authors: Leedgaard, J. (Ekstern), Mortensen, K. H. (Ekstern), Larsen, A. (Intern), Larsen, J. (Intern)
Publication date: 2002

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Disruption management

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Organisations: Operations Research, Department of Informatics and Mathematical Modeling, Department of Transport
Authors: Clausen, J. (Intern), Hansen, J. (Intern), Larsen, J. (Intern), Larsen, A. (Intern)
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Original language: English
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Disruption management - operations research between planning and execution

General information
Lagrangean Duality Applied on Vehicle Routing with Time Windows - Experimental Results

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Authors: Kallehauge, B. (Intern), Larsen, J. (Intern), Madsen, O. B. (Intern)
Publication date: 2001

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Publication: Research › Report – Annual report year: 2001

Using heuristics to solve the dedicated aircraft recovery problem
The Dedicated Aircraft Recovery Problem (DARP) involves decisions concerning aircraft to flight assignments in situations where unforeseen events have disrupted the existing flight schedule, e.g. bad weather causing flight delays. The dedicated aircraft recovery problem aims to recover these flight schedules through a series of reassignments of aircraft to flights, delaying of flights and cancellations of flights. This article describes an effective method to solve DARP. A heuristic is implemented, which is able to generate feasible revised flight schedules of good quality in less than 10 seconds when applied to real flight schedules with disruptions from British Airways. The heuristic is able to consider delays, cancellations and reassignments simultaneously and balance the trade-off between these options. It is also demonstrated that different strategies can be applied to prioritize these options when generating the revised flight schedules without affecting the solution time required.

General information
State: Published
Organisations: Operations Research, Department of Informatics and Mathematical Modeling, COOP, Carmen System A.B.
Authors: Løve, M. (Ekstern), Sørensen, K. R. (Ekstern), Larsen, J. (Intern), Clausen, J. (Intern)
Publication date: 2001

Publication information
Original language: English
Main Research Area: Technical/natural sciences
Electronic versions:
imm138.pdf
Links:
Source: orbit
Source-ID: 58024
Publication: Research › Report – Annual report year: 2001
Using Parallel Computers to solve the Vehicle Routing Problem with Time Windows

General information
State: Published
Organisations: Operations Research, Department of Informatics and Mathematical Modeling, Logistics & ITS, Department of Transport
Authors: Larsen, J. (Intern), Clausen, J. (Intern), Madsen, O. B. (Intern)
Publication date: 2000

Publication information
Publisher: Informatics and Mathematical Modelling, Technical University of Denmark, DTU
Original language: English
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 200948
Publication: Research - peer-review › Report – Annual report year: 2000

Parallelization of the Vehicle Routing Problem with Time Windows
This dissertation presents a number of algorithms for solving the Vehicle Routing Problem with Time Windows (VRPTW). The VRPTW is a generalization of the well known capacity constrained Vehicle Routing Problem (VRP). In the VRP a fleet of vehicles based at a central depot must service a set of customers. In the VRPTW each customer has a time window. Service of a customer must begin within the interval given by the time window. The objective is to minimize some aspect of operating costs (e.g. total distance traveled, number of vehicles needed or a combination of parameters). Since the late 80's and the beginning of the 90's optimal methods for the VRPTW have appeared in the literature. Methods have basically been based on three approaches: dynamic programming, Lagrange relaxation and column generation (Dantzig-Wolfe). The most successful approaches rely on column generation. Good results have also been obtained using Lagrange relaxation. This dissertation is divided into three parts. First the theoretical framework is described. Thereafter a number of techniques to improve the performance of the column-generation framework are proposed and analyzed. Finally a parallel algorithm based on the sequential algorithm developed in the previous part of the dissertation is developed and analyzed.

Experiments with the auction algorithm for the shortest path problem
The auction approach for the shortest path problem (SPP) as introduced by Bertsekas is tested experimentally. Parallel algorithms using the auction approach are developed and tested. Both the sequential and parallel auction algorithms perform significantly worse than a state-of-the-art Dijkstra-like reference algorithm. Experiments are run on a distributed-memory MIMD class Meiko parallel computer.

General information
State: Published
Organisations: Operations Research, Department of Informatics and Mathematical Modeling
Authors: Larsen, J. (Intern), Pedersen, I. (Ekstern)
Publication date: May 1999

Publication information
Original language: English
Series: IMM-PHD-1999-62
Main Research Area: Technical/natural sciences
Electronic versions:
imm140.pdf
Source: orbit
Source-ID: 200819
Publication: Research › Ph.D. thesis – Annual report year: 1999

Experiments with the auction algorithm for the shortest path problem
The auction approach for the shortest path problem (SPP) as introduced by Bertsekas is tested experimentally. Parallel algorithms using the auction approach are developed and tested. Both the sequential and parallel auction algorithms perform significantly worse than a state-of-the-art Dijkstra-like reference algorithm. Experiments are run on a distributed-memory MIMD class Meiko parallel computer.

General information
State: Published
Organisations: Operations Research, Department of Informatics and Mathematical Modeling
Authors: Larsen, J. (Intern), Pedersen, I. (Ekstern)
Pages: 403-421
Publication date: 1999
Main Research Area: Technical/natural sciences

Publication information
Journal: Nordic Journal of Computing
A note on the practical performance of the auction algorithm for the shortest path

The performance of the auction algorithm for the shortest path problem has previously been investigated in four papers. Here the results of a series of new experiments with the code from the two most recent papers are reported. Experiments clearly show that the auction algorithm is inferior to the state-of-the-art shortest path algorithms.
A parallel approach to the stable marriage problem

This paper describes two parallel algorithms for the stable marriage problem implemented on a MIMD parallel computer. The algorithms are tested against sequential algorithms on randomly generated and worst-case instances. The results clearly show that the combination of a very simple problem and a commercial MIMD system results in parallel algorithms which are not competitive with sequential algorithms wrt. practical performance.

1 Introduction

In 1962 the Stable Marriage Problem was...
Managing Cyber Risk and Security in the Global Supply Chain
Department of Management Engineering
Period: 01/11/2014 → 31/10/2017
Number of participants: 6
Phd Student: Sepúlveda Estay, Daniel Alberto (Intern)
Supervisor: Khan, Omera (Intern)
Main Supervisor: Larsen, Jesper (Intern)
Examiner: Oehmen, Josef (Intern)
Urciuoli, Luca (Ekstern)
Wieland, Andreas (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: Institut stipendie (DTU)

Relations
Activities:
Massachusetts Institute of Technology
Project: PhD

Dynamic University Timetabling
Department of Management Engineering
Period: 01/02/2014 → 18/05/2017
Number of participants: 9
Phd Student: Lindahl, Michael (Intern)
Supervisor: Herold, Michael Bigom (Ekstern)
Ho, Sin C. (Ekstern)
Kristiansen, Simon (Intern)
Sørensen, Matias (Intern)
Main Supervisor: Stidsen, Thomas Jacob Riis (Intern)
Examiner: Larsen, Jesper (Intern)
Berghe, Greet Vanden (Ekstern)
Hasle, Geir (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: Industrial PhD

Relations
Publications:
Strategic, Tactical and Operational University Timetabling
Project: PhD

Robustness in Railway Planning
Department of Management Engineering
Period: 01/05/2013 → 01/09/2016
Number of participants: 5
Phd Student:
**Integrated Optimisation of Vehicle Resources in Urban Rail Transport Systems**

Department of Management Engineering  
Period: 01/08/2012 → 23/03/2017  
Number of participants: 6  
PhD Student:  
Thorlacius, Per (Intern)  
Supervisor:  
Groth, Julie Jespersen (Intern)  
Main Supervisor:  
Larsen, Jesper (Intern)  
Examiner:  
Røpke, Stefan (Intern)  
Krasemann, Johanna Törnquist (Ekstern)  
Mannino, Carlo (Ekstern)

**Financing sources**  
Source: Internal funding (public)  
Name of research programme: Institut stipendie (DTU) Samf.  
Project: PhD

**Integreeret disponering/genoppretning af togdrift**

Department of Management Engineering  
Period: 01/08/2012 → 11/12/2015  
Number of participants: 6  
PhD Student:  
Haahr, Jørgen Thorlund (Intern)  
Supervisor:  
Larsen, Jesper (Intern)  
Main Supervisor:  
Pisinger, David (Intern)  
Examiner:  
Røpke, Stefan (Intern)  
Borndörfer, Ralf (Ekstern)  
Huisman, Dennis (Ekstern)

**Financing sources**  
Source: Internal funding (public)  
Name of research programme: Institut stipendie (DTU) Samf.  
Project: PhD
Development of a Generic Performance Measurement Model in an Emergency Department

Department of Management Engineering
Period: 01/04/2012 → 18/06/2015
Number of participants: 7
Phd Student:
Serup, Christian Michel (Intern)

Supervisor:
Forberg, Jakob Lundager (Ekstern)
Ravn, Lisbet Isenberg (Ekstern)

Main Supervisor:
Jacobsen, Peter (Intern)

Examiner:
Larsen, Jesper (Intern)
Ceglarek, Dariusz J. (Ekstern)
Laursen, Jens Ole (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: 1/3 FUU, 1/3 inst 1/3 Andet
Project: PhD

Optimal Aircraft Gate Assignment on a Strategic, Tactical and Operational Level

Department of Management Engineering
Period: 01/10/2010 → 26/05/2014
Number of participants: 7
Phd Student:
Justesen, Tor Fog (Intern)

Supervisor:
Dohn, Anders Høeg (Intern)
Meincke, Dan (Ekstern)

Main Supervisor:
Larsen, Jesper (Intern)

Examiner:
Larsen, Allan (Intern)
Cohn, Amy Ellen Mainville (Ekstern)
Vaaben, Bo Valdemar (Intern)

Financing sources
Source: Internal funding (public)
Name of research programme: ErhvervsPhD-ordningen VTU
Project: PhD

Udvikling af optimeringsmodeller og løsningsmetoder til ruteplanlægning inden for trampfart

Department of Management Engineering
Period: 01/01/2010 → 19/12/2014
Number of participants: 5
Phd Student:
Vilhelmsen, Charlotte (Intern)

Main Supervisor:
Larsen, Jesper (Intern)

Examiner:
Pisinger, David (Intern)
Andersson, Henrik (Ekstern)
Oliveria, José Fernando da (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: Institut stipendie (DTU) Samf.
Sustainable Disruption Management
Department of Management Engineering
Period: 01/11/2009 → 04/04/2013
Number of participants: 7
Phd Student:
Vaaben, Bo Valdemar (Intern)
Supervisor:
Altus, Stephen (Ekstern)
Hansen, Jesper (Intern)
Main Supervisor:
Larsen, Jesper (Intern)
Examiner:
Larsen, Allan (Intern)
Cohn, Amy E. M. (Ekstern)
Granberg, Tobias A. (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: ErhvervsPhD-ordningen VTU
Project: PhD

Solving Recovery Problems using Optimisation Methods
Department of Management Engineering
Period: 01/05/2008 → 28/09/2011
Number of participants: 6
Phd Student:
Rasmussen, Matias Sevel (Intern)
Supervisor:
Ryan, David (Ekstern)
Main Supervisor:
Larsen, Jesper (Intern)
Examiner:
Larsen, Allan (Intern)
Gustafsson, Tomas (Ekstern)
Rönnqvist, Mikael (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: Institut stipendie (DTU)
Project: PhD

Modeller og Metoder for optimisationsproblemer med kombineret resourceplanlægning og skedulering
Department of Management Engineering
Period: 01/12/2006 → 01/09/2010
Number of participants: 5
Phd Student:
Dohn, Anders Høeg (Intern)
Supervisor:
Larsen, Jesper (Intern)
Main Supervisor:
Clausen, Jens (Intern)
Examiner:
Rönnqvist, Mikael (Ekstern)
vanden Akker, J. M. (Ekstern)
Financing sources
Source: Internal funding (public)
Name of research programme: DTU-lønnet stipendie
Project: PhD

Models and Algorithms for the Vehicle Routing Problem with Cross Docking
Department of Management Engineering
Period: 01/02/2006 → 24/03/2010
Number of participants: 6
Phd Student: Wen, Min (Intern)
Supervisor: Clausen, Jens (Intern)
Main Supervisor: Larsen, Jesper (Intern)
Examiner: Larsen, Allan (Intern)
Hasle, Geir (Ekstern)
Nielsen, Jakob Birkedal (Intern)

Financing sources
Source: Internal funding (public)
Name of research programme: DTU-lønnet stipendie
Project: PhD

Beslutningsstøtte til genopretning ved uregelmæssigheder i togdrift
Department of Management Engineering
Period: 01/10/2005 → 22/04/2009
Number of participants: 6
Phd Student: Groth, Julie Jespersen (Intern)
Supervisor: Clausen, Jens (Intern)
Main Supervisor: Larsen, Jesper (Intern)
Examiner: Stidsen, Thomas Jacob Riis (Intern)
Abbink, Erwin Jan W. (Ekstern)
Liebchen, Christian (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: ErhvervsPhD-ordningen VTU
Project: PhD

Disruption Management i transportsektoren
Department of Informatics and Mathematical Modeling
Period: 01/04/2003 → 01/07/2009
Number of participants: 6
Phd Student: Wanscher, Jørgen (Intern)
Supervisor: Clausen, Jens (Intern)
Main Supervisor: Larsen, Jesper (Intern)
Examiner: Stidsen, Thomas Jacob Riis (Intern)
Ikke-differentiabel optimering i heltalsprogrammering

Department of Transport
Period: 01/08/2000 → 22/05/2006
Number of participants: 7
Phd Student:
Kallehauge, Brian (Intern)
Supervisor:
Larsen, Jesper (Intern)
Madsen, Kaj (Intern)
Main Supervisor:
Madsen, Oli B.G. (Intern)
Examiner:
Nielsen, Otto Anker (Intern)
Lübbecke, Marco (Ekstern)
Pisinger, David (Intern)

Financing sources
Source: Internal funding (public)
Name of research programme: Forskningsrådsfinansiering
Project: PhD

PARELLELIZATION OF THE VEHICLE ROUTING PROBLEM WITH TIME WINDOWS

Department of Informatics and Mathematical Modeling
Period: 01/01/1998 → 30/09/1999
Number of participants: 2
Phd Student:
Larsen, Jesper (Intern)
Main Supervisor:
Clausen, Jens (Intern)

Financing sources
Source: Internal funding (public)
Name of research programme: Forskningsrådsfinansiering
Project: PhD

Vehicle routing with time windows.
The purpose of the project is to develop and test optimal solution methods to vehicle routing problems with customer time windows. A method based on Dantzig-Wolfe decomposition, generation of valid inequalities, and branch and bound is developed. The results are very promising and the algorithm turns out to be faster than other algorithms considered in the literature, and several previously unsolved problems has been solved to optimality. For the time being we are improving the branch and bound procedure and implementing a parallel branch and bound.
Activities:

**Tramp ship routing and scheduling with voyage separation requirements**

*Period: 17 Jul 2017*

Jesper Larsen (Guest lecturer)
Charlotte Vilhelmsen (Other)
Richard Martin Lusby (Other)

Department of Management Engineering
Management Science
Transport DTU
Operations Research

**Description**

This presentation addresses a tramp routing and scheduling problem. Tramp ships operate like taxis by following the available demand, as opposed to liner ships that operate like busses on a fixed route network according to a published timetable. Tramp operators determine some of the demand in advance by ensuring long-term contracts. The rest of the demand comes from optional voyages found in the spot market. Routing and scheduling a tramp feet to best utilize feet capacity according to the current demand is therefore an ongoing and complicated problem. We add further complexity by incorporating voyage separation requirements that enforce a minimum time spread between some voyages. We developed a new and exact Branch-and-Price procedure for this problem. A dynamic programming algorithm generates columns, while a novel time window branching scheme is used to enforce the voyage separation requirements. Computational results show that the algorithm finds optimal solutions very quickly for the vast majority of test instances. We compare the results with two earlier published methods and show that our Branch-and-Price approach outperforms both an a priori path generation method and an Adaptive Large Neighbourhood Search heuristic.

**Degree of recognition:** International

**Related event**

**IFORS 2017: 21st Conference of the International Federation of Operations and Research**

17/07/2017 → 21/07/2017
Québec City, Canada

Activity: Talks and presentations › Conference presentations

**Planning of Midwives**

*Period: 4 Jul 2016*

Charlotte Vilhelmsen (Speaker)
Jesper Larsen (Other)

Department of Management Engineering
Management Science
Operations Research

**Description**

At a hospital in Denmark around 40 midwives support the pregnancy of approx. 6000 pregnant women every year. Their role is to monitor the pregnancies and prepare the women for labour. Based on the due date of a woman, authority guidelines prescribe specific and mostly rather narrow time windows within which the pregnant woman should have consultations with a midwife. Therefore, once a pregnant woman enters the system, here sequence of consultations for the time period until labour is fairly fixed. There is a clear goal that, as far as possible, each pregnant woman should see the same midwife at every consultation. Every week the newly arrived pregnant women are assigned an arbitrary free time slot belonging to a specific midwife. In turn this midwife is expected to have consultations with this woman in specific weeks according to the authority guidelines. This random assignment of pregnant woman to specific midwives, without any concern to the midwives’ future schedules, means that each midwife has a very unbalanced workload over the year. Furthermore, it means that there is an imbalance between the workloads of the different midwives. The aim of this project is therefore to devise a method that can make a fair distribution of pregnant women among the midwives. The distribution should result in a balanced work load for each midwife and a balanced work load among the midwives while at the same time making sure that the time windows for consultations are not violated.

**Degree of recognition:** International
Related event

28th European Conference on Operational Research
03/07/2016 → 07/07/2016
Poznan, Poland
Activity: Talks and presentations › Conference presentations

The 9th Triennial Symposium on Transportation Analysis (TRISTAN) (External organisation)
Period: 12 Jun 2016
Jesper Larsen (Participant)
Department of Management Engineering
Management Science
Description
Member of the the scientific program committee
Degree of recognition: International
Links:
http://tristan-symposium.org/

Related external organisation

The 9th Triennial Symposium on Transportation Analysis (TRISTAN)
Activity: Membership › Membership of committees, commissions, boards, councils, associations, organisations, or similar

OptALI Industry Day
Period: 1 Jun 2015 → 2 Jun 2015
Jesper Larsen (Organizer)
Department of Management Engineering
Management Science
Description
Chair of the organisation of the OptALI Industry Days here at DTU

Related event

OptALI Industry Day
01/06/2015 → 02/06/2015
Lyngby, Denmark
Activity: Attending an event › Participating in or organising a conference