A matheuristic for the driver scheduling problem with staff cars

In the public bus transport industry, it is estimated that the cost of a driver schedule accounts for approximately 60% of a transport company’s operational expenses. Hence, it is important for transport companies to minimize the overall cost of driver schedules. A duty is defined as the work of a driver for a day and the driver scheduling problem (DSP) is concerned with finding an optimal set of driver duties to cover a set of timetabled bus trips. Numerous labor regulations and other practical conditions enforce drivers to travel within the city network to designated bus stops to start/end duty, to take a break or to takeover a bus from another driver. This paper focuses on the driver scheduling problem with staff cars (DSPSC), where staff cars can be utilized by the drivers to fulfill their travel activities. However, staff cars should always be returned to the depot and can perform multiple round trips during the day. The problem is restricted by the number of cars available at the depot. We present a matheuristic for solving the DSPSC and the proposed method is tested on instances from Danish and Swedish companies. A comparison with a state-of-the-art mixed integer programming (MIP) solver indicates that the matheuristic provides better solutions, with comparable computation times, for 6 out of 10 large instances. For instances that have more than 6 staff cars and 1200 bus trips, the improvement is 13-15% on average.
A matheuristic for the driver scheduling problem with staff cars

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General information
State: Published
Contributors: Govinda Raja Perumal, S. S., Larsen, J., Lusby, R. M., Riis, M., Sørensen, K.
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Assignment of Pregnant Women to Midwives

Based on the due date of a pregnant woman Danish Health Authority guidelines prescribe time windows for when the woman should have midwife consultations. A principle of continuity of care means that each woman should preferably see the same midwife at every consultation. For the first consultation 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 authority guidelines. This random assignment of pregnant women to midwives means that each midwife has a very unbalanced workload and that there is an imbalance between the workloads of different midwifes within each week. The aim of this work is to devise a method for assigning and scheduling midwife consultations that results in a balanced workload for each midwife and among the midwives while making sure consultation guidelines are respected. We present a mathematical model for this problem and through simulation of the historical flow of pregnant women show that using this model would have significantly reduced workload imbalances, even when including a further restriction not currently adhered to. The model is too demanding to be implemented at the hospital. Therefore, we develop an assignment tool based on full enumeration for one pregnant woman at a time. Simulations show that this approach can still reduce workload imbalances considerably. The tool, which has now been implemented at the hospital, is also used to test the workload impact of continuity of care.

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Organisations: Department of Management Engineering, Management Science, Operations Research, Transport DTU, Technical University of Denmark
Contributors: Græse, L., Vilhelmsen, C., Larsen, J.
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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.

**General information**

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Web of Science (2018): Indexed yes

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Scopus rating (2017): CiteScore 4.08 SJR 2.437 SNIP 2.375
Web of Science (2017): Impact factor 3.428
Web of Science (2017): Indexed yes

BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 3.83 SJR 2.489 SNIP 2.433
Web of Science (2016): Impact factor 3.297
Web of Science (2016): Indexed yes

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Scopus rating (2015): CiteScore 3.59 SJR 2.225 SNIP 2.364
Web of Science (2015): Impact factor 2.679
Web of Science (2015): Indexed yes

BFI (2014): BFI-level 1
Scopus rating (2014): CiteScore 3.21 SJR 2.143 SNIP 2.444
Web of Science (2014): Impact factor 2.358
Web of Science (2014): Indexed yes

BFI (2013): BFI-level 1
Scopus rating (2013): CiteScore 3.25 SJR 2.238 SNIP 2.691
Web of Science (2013): Impact factor 1.843
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes

BFI (2012): BFI-level 1
Scopus rating (2012): CiteScore 3.01 SJR 2.328 SNIP 2.567
Web of Science (2012): Impact factor 2.038
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes

BFI (2011): BFI-level 1
Scopus rating (2011): CiteScore 3.02 SJR 2.352 SNIP 2.422
Web of Science (2011): Impact factor 1.815
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes

BFI (2010): BFI-level 1
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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Original language: English
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Source-ID: 134308331
Research output: Research › Report – Annual report year: 2018

Equidistant representations: connecting coverage and uniformity in biobjective optimization

The nondominated frontier of a multiobjective optimization problem can be overwhelming to a decision maker, as it is often either very large or infinite in size. Instead, a discrete representation of this set in the form of a small sample of points is often preferred. In this paper we consider the Discrete Representation Problem (DRP), which is itself a triobjective optimization problem. The three objectives comprise three standard quality measures for discrete representations, namely coverage, uniformity and the cardinality of the set. We introduce the notion of complete equidistant representations, and prove that such a representation provides a nondominated solution to the DRP. In addition, we show through the help of
complete equidistant representations that coverage and uniformity can be seen as dual problems given a fixed cardinality, and therefore that optimality gaps for coverage and uniformity can be obtained given any representation. Moreover, even though the definition of the coverage error requires the full nondominated set, we show how the coverage error for a given representation can be calculated by generating a much smaller set. Finally, we present a new method for finding discrete representations of a desired cardinality that outperforms existing methods w.r.t. coverage and uniformity on a set of mixed-integer programming benchmark instances.

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ramoo_abstract_kidd.pdf
Source: PublicationPreSubmission
Source-ID: 161209530
Research output: Research - peer-review › Paper – Annual report year: 2018

Passenger- and operator-oriented 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 talk we present a multiobjective mixed-integer programming formulation for the scheduling of 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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Organisations: Department of Management Engineering, Management Science, Operations Management, Operations Research, Transport DTU
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Source: PublicationPreSubmission
Source-ID: 161209699
Research output: Research - peer-review › Conference abstract for conference – Annual report year: 2018

Planning and scheduling operating rooms for elective and emergency surgeries with uncertain duration
In this paper we investigate the planning of operating rooms at Rigshospitalet, a large Danish hospital. Each operation must be assigned to a specific operating room and also be scheduled for a specific time while taking into account clinical guidelines. Both elective and emergency operations are included, such that the elective operations are planned while still taking potential emergency operations into consideration. Furthermore, the duration of each operation is uncertain. The aim is to construct robust operating room schedules that minimise overtime work and release unused capacity.

Due to the uncertainty associated with arrival of emergency patients and also the duration of each operation, a deterministic model is not suitable for this problem. Therefore, we develop a stochastic model where operation duration can vary and where the arrivals of emergency patients are unknown. The stochastic model is computationally heavy, so two mixed integer programming based heuristics denoted 2-Step Relax-and-Fix and All Open Relax-and-Fix are developed to solve the problem.

The computational study is based on an extensive dataset compromising 304 days. The heuristics give good results with half of the operating rooms having less than 8 min of overtime work. To test the robustness of the solutions we carry out a simulated implementation of the operation plans. The simulation shows that the heuristic solutions are fairly robust. In general, results show a clear potential for implementing the method for planning and scheduling of operating rooms at Rigshospitalet.
Rolling Stock Scheduling with Maintenance Requirements at the Chinese High Speed Railway

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Organisations: Department of Management Engineering, Management Science, Operations Research, Southwestern Jiaotong University
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Research output: Research - peer-review › Sound/Visual production (digital) – Annual report year: 2018

Rolling ship routing and scheduling with voyage separation requirements
This presentation addresses a tramp routing and scheduling problem. Tramp ships operate like taxies 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.

General information
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.
Tramp ship routing and scheduling with voyage separation requirements

In this paper we explore tramp ship routing and scheduling. Tramp ships operate much like taxies 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.
Tramp ship routing and scheduling with voyage separation requirements
This presentation addresses a tramp routing and scheduling problem. Tramp ships operate like taxies 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 an a priori path generation method and an Adaptive Large Neighbourhood Search heuristic.

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.
Publications information
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Volume: 65
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Web of Science (2019): Indexed yes
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Scopus rating (2017): CiteScore 3.75 SJR 1.916 SNIP 2.094
Web of Science (2017): Impact factor 2.962
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 3.77 SJR 2.299 SNIP 2.192
Web of Science (2016): Impact factor 2.6
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): CiteScore 3.09 SJR 1.924 SNIP 2.048
Web of Science (2015): Impact factor 1.988
BFI (2014): BFI-level 1
Scopus rating (2014): CiteScore 3.12 SJR 2.225 SNIP 2.309
Web of Science (2014): Impact factor 1.861
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): CiteScore 3.62 SJR 2.527 SNIP 2.93
Web of Science (2013): Impact factor 1.718
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): CiteScore 3.36 SJR 2.727 SNIP 2.775
Web of Science (2012): Impact factor 1.909
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 1
Scopus rating (2011): CiteScore 3.05 SJR 2.41 SNIP 2.449
Web of Science (2011): Impact factor 1.72
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 1
Scopus rating (2010): SJR 2.316 SNIP 2.449
Web of Science (2010): Impact factor 1.769
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 1
Scopus rating (2009): SJR 2.28 SNIP 2.389
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 1
Scopus rating (2008): SJR 2.199 SNIP 2.287
An adaptive large neighborhood search procedure applied to the dynamic patient admission scheduling problem

General information
State: Published
Organisations: Department of Management Engineering, Management Science, AMCS Denmark A/S, Hospital South West Jutland
Contributors: Lusby, R. M., Schwierz, M., Range, T. M., Larsen, J.
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Peer-reviewed: Yes

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Volume: 74
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Web of Science (2018): Indexed yes
BFI (2017): BFI-level 2
Scopus rating (2017): CiteScore 3.2 SJR 0.766 SNIP 1.569
Web of Science (2017): Impact factor 2.879
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 2.65 SJR 0.635 SNIP 1.251
Web of Science (2016): Impact factor 2.009
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): CiteScore 3.04 SJR 0.797 SNIP 1.785
Web of Science (2015): Impact factor 2.142
BFI (2014): BFI-level 2
Scopus rating (2014): CiteScore 2.83 SJR 0.787 SNIP 1.896
Web of Science (2014): Impact factor 2.019
BFI (2013): BFI-level 2
Scopus rating (2013): CiteScore 2.57 SJR 0.697 SNIP 1.661
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 decision selecting lines from a predefined pool. We show results directly applying this model to a Copenhagen commuter rail problem.

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Source: FindIt
Source-ID: 2349017112
Research output: Research - peer-review › Journal article – Annual report year: 2016

An applied optimization based method for line planning to minimize travel time
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 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.
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 infinite 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.

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Source-ID: 127599433
Research output: Research › Report – Annual report year: 2016

Joint overbooking and seat allocation for fare families
Relevance and resource 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, her 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...
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.

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Publication date: 2015

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Original language: English
Electronic versions:
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Research output: Research › Report – Annual report year: 2015

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%.

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Organisations: Department of Management Engineering, Management Science, DSB, IBM Zurich Research Laboratory
Contributors: Thorlacius, P., Larsen, J., Laumanns, M.
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BFI (2018): BFI-level 1
BFI (2017): BFI-level 1
Scopus rating (2017): CiteScore 1.69 SJR 0.996 SNIP 1.477
BFI (2016): BFI-level 1
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Scopus rating (2015): CiteScore 1.87 SJR 0.86 SNIP 1.144
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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%.

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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.

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Publisher: Erasmus University
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.

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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.

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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 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. 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.

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.
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.
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. A major challenge when operating such ships is how to best allocate cargoes to available tanks while taking 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 more 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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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 seconds 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.

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.
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.

### 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 modifications to the CUCTT problem usually described in the literature. One of the major differences is that the assignment of the courses to specific time slots is 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.
Tramp Ship Routing and Scheduling - Incorporating Additional Complexities

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. 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.

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 taxies 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 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.

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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 six out of six instances from a publicly available repository.

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Publication date: 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.
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.

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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 (SMCPS) 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.
The Rolling Stock and Depot Recovery Problem

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The Tank Allocation Problem in Bulk Shipping

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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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<td>CiteScore 0.773 SNIP 0.993</td>
<td>Impact factor 0.842</td>
<td>BFI-level 2</td>
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Original language: English
Keywords: column generation, manpower planning, optimization, cutting stock problem
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.

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Organisations: Department of Management Engineering, Management Science
Contributors: Rasmussen, M. S., Justesen, T. F., Dohn, A. H., Larsen, J.
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Web of Science (2016): Indexed yes
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Scopus rating (2014): CiteScore 3.21 SJR 2.143 SNIP 2.444
Web of Science (2014): Impact factor 2.358
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
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 wellknown 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.

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.

A multilevel variable neighborhood search heuristic for a practical vehicle routing and driver scheduling problem

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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
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
State: Published
Organisations: Logistics & ITS, Department of Transport, Operations Research, Department of Management Engineering, Technical University of Denmark
Contributors: Buhrkal, K. F., Zuglian, S., Repk, S., Larsen, J., Lusby, R. M.
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Publication date: 2011
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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.
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.
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.

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. NETWORKS, Vol. 58(4), 273–289 2011
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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BFI (2018): BFI-level 1
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 1
Scopus rating (2017): CiteScore 1.84 SJR 1.071 SNIP 1.404
Web of Science (2017): Impact factor 2.4
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 1.72 SJR 0.969 SNIP 1.153
Web of Science (2016): Impact factor 1.745
BFI (2015): BFI-level 1
Scopus rating (2015): CiteScore 1.62 SJR 1.06 SNIP 1.14
Web of Science (2015): Impact factor 1.255
BFI (2014): BFI-level 1
Scopus rating (2014): CiteScore 1.23 SJR 0.747 SNIP 1.137
Web of Science (2014): Impact factor 0.977
BFI (2013): BFI-level 1
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Web of Science (2013): Impact factor 0.481
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BFI (2012): BFI-level 1
Scopus rating (2012): CiteScore 0.68 SJR 0.67 SNIP 0.846
Web of Science (2012): Impact factor 0.588
ISI indexed (2012): ISI indexed no
BFI (2011): BFI-level 1
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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2010_10.pdf
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http://www.man.dtu.dk/upload/institutter/ipl/publ/publikationer%202010/rapport%209.pdf
Source: orbit
Source-ID: 260235
Research output: Research › Report – Annual report year: 2010
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.

General information

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Web of Science (2018): Indexed yes
BFI (2017): BFI-level 1
Scopus rating (2017): CiteScore 3.75 SJR 1.916 SNIP 2.094
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Web of Science (2017): Indexed yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 3.77 SJR 2.299 SNIP 2.192
Web of Science (2016): Impact factor 2.6
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): CiteScore 3.09 SJR 1.924 SNIP 2.048
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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State: Published
Organisations: Operations Research, Department of Management Engineering, University of Auckland
Contributors: Rasmussen, M. S., Ryan, D. M., Lusby, R. M., Larsen, J.
Pages: 539-541
Publication date: 2010

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.

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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 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.

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Electronic versions:
2010_11.pdf
URLs:
Source: orbit
Source-ID: 262181
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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http://www.man.dtu.dk/upload/institutter/ipl/publ/publikationer%202009/rapport%209.pdf
Source: orbit
Source-ID: 253674
Research output: Research › Report – Annual report year: 2009

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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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.

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Original language: English
(DTU Management 2009; No. 15).
Keywords: disruption management, train routing, optimization, duality

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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Organisations: Logistics & ITS, Department of Transport, Operations Research, Department of Management Engineering, Technical University of Denmark
Contributors: Buhrkal, K., Zuglian, S., Røpke, S., Larsen, J., Lusby, R. M.
Number of pages: 25
Publication date: 2009
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.

General information
State: Published
Organisations: Operations Research, Department of Management Engineering, University of Auckland
Contributors: Lusby, R. M., Larsen, J., Ehrgott, M., Ryan, D.
Number of pages: 29
Publication date: 2009

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http://www.man.dtu.dk/upload/institutter/ipl/publ/publikationer%202009/rap3%20samlet%202009%205t.pdf
Source: orbit
Source-ID: 251477
Research output: Research - peer-review › Report – Annual report year: 2009

Rolling Stock Recovery Problem

General information
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Organisations: Operations Research, Department of Management Engineering
Contributors: Groth, J. J., Clausen, J., Larsen, J.
Number of pages: 54
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Research output: Research › Report – Annual report year: 2009

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.
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 time horizon. Customer orders and their feasible service periods are 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 house 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.

General information
State: Published
Organisations: Operations Research, Department of Management Engineering
Contributors: Rasmussen, M. S., Dohn, A. H., Larsen, J.
Publication date: 2009
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.

General information

State: Published
Organisations: Logistics & ITS, Department of Transport, Operations Research, Department of Management Engineering, HEC Montreal
Contributors: Wen, M., Larsen, J., Clausen, J., Cordeau, J., Laporte, G.
Pages: 1708-1718
Publication date: 2009
Peer-reviewed: Yes
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
Contributors: Warberg, A., Larsen, J., Jørgensen, R. M.
Publication date: 2008

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Original language: English
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The Home Care Crew Scheduling Problem

General information
State: Published
Organisations: Operations Research, Department of Management Engineering, Technical University of Denmark
Contributors: Hansen, A. D., Rasmussen, M. S., Justesen, T., Larsen, J.
Publication date: 2008

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Source-ID: 220681
Research output: Research - peer-review › Article in proceedings – Annual report year: 2008

The Home Care Crew Scheduling Problem

General information
State: Published
Organisations: Department of Management Engineering, Operations Research, SAS
Contributors: Dohn, A. H., Rasmussen, M. S., Justesen, T., Larsen, J.
Pages: 19-23
Publication date: 2008
Peer-reviewed: Unknown

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Journal: ORbit : medlemsblad for Dansk Selskab for Operationsanalyse
Volume: 13
ISSN (Print): 1601-8893
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Web of Science (2003): Indexed yes
Original language: English
Source: orbit
Source-ID: 271764
Research output: Communication › Journal article – Annual report year: 2008

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, Logistics & ITS, Department of Transport, Operations Research, British Airways, Carmen System A.B.
Contributors: Kohl, N., Larsen, A., Larsen, J., Ross, A., Tiourine, S.
Pages: 149-162
Publication date: May 2007
Peer-reviewed: Yes

Publication information
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.

General information

State: Published
Organisations: Department of Informatics and Mathematical Modeling, Operations Research
Contributors: Thomadsen, T., Larsen, J.
Pages: 2520-2531
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Peer-reviewed: Yes

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Scopus rating (2017): CiteScore 3.75 SJR 1.916 SNIP 2.094
Web of Science (2017): Impact factor 2.962
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 1
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Web of Science (2016): Impact factor 2.6
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): CiteScore 3.09 SJR 1.924 SNIP 2.048
Web of Science (2015): Impact factor 1.988
BFI (2014): BFI-level 1
Scopus rating (2014): CiteScore 3.12 SJR 2.225 SNIP 2.309
Web of Science (2014): Impact factor 1.861
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): CiteScore 3.62 SJR 2.527 SNIP 2.93
Web of Science (2013): Impact factor 1.718
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): CiteScore 3.36 SJR 2.727 SNIP 2.775
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.

General information
State: Published
Organisations: Department of Transport, Operations Research, Department of Informatics and Mathematical Modeling
Contributors: Jørgensen, R. M., Larsen, J., Bergvinsdottir, K. B.
Pages: 1321-1331
Publication date: 2007
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.
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: Department of Informatics and Mathematical Modeling, University of Southern Denmark
Contributors: Clausen, J., Larsen, J., Bang-Jenssen, J.
Publication date: 2006
Peer-reviewed: Unknown

Publication information
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Ratings:
ISI indexed (2013): ISI indexed no
ISI indexed (2012): ISI indexed no
ISI indexed (2011): ISI indexed no
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.
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 therebye 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.
Recent Advances in the Vehicle Routing Problem with Time Windows

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.

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.
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.

An exact algorithm for Aircraft Landing Problem

The problem of aircraft landing is an important aspect of air traffic management. The objective is to assign landing slots to aircraft in such a way that the constraints of runway availability, minimum time intervals between successive landings, and other operational constraints are satisfied. This paper presents an exact algorithm for solving the aircraft landing problem, which is based on a mixed-integer linear programming formulation. The algorithm is tested on a set of benchmark instances, and the results are compared with those obtained by other methods. The proposed algorithm is shown to be effective in solving large instances of the problem to optimality.
Disruption Management in the Airline Industry - Concepts, Models and Methods

General information
State: Published
Organisations: Operations Research, Department of Informatics and Mathematical Modeling
Contributors: Clausen, J., Larsen, A., Larsen, J.
Publication date: 2005

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Source: orbit
Source-ID: 185941
Research output: Research - peer-review › Report – Annual report year: 2005

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
Contributors: Kallehauge, B., Larsen, J., Madsen, O. B., Solomon, M.
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Publisher: Springer
Editors: Desaulniers, G., Desrosiers, J., Solomon, M. M.
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Source-ID: 185809
Research output: Research - peer-review › Book chapter – Annual report year: 2005

Using Heuristics to Solve the Dedicated Aircraft Recovery Problem

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Organisations: Operations Research, Department of Informatics and Mathematical Modeling
Contributors: Løve, M., Sørensen, K. R., Larsen, J., Clausen, J.
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Web of Science (2019): Indexed yes
BFI (2018): BFI-level 1
Web of Science (2018): Indexed yes
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

Contributors: Kohl, N., Larsen, A., Larsen, J., Ross, A., Tiourine, S.

Number of pages: 36
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.

Refronements 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.
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
State: Published
Organisations: Operations Research, Department of Informatics and Mathematical Modeling, Department of Transport
Contributors: Bergvinsdottir, K. B., Larsen, J., Jørgensen, R. M.
Publication date: 2004

Publication information
Place of publication: Lyngby
Publisher: Informatics and Mathematical Modelling, Technical University of Denmark, DTU
Original language: English
Electronic versions: imm3395.pdf
imm3395.ps
URLs:
Source: orbit
Source-ID: 154841
Research output: Research - peer-review → Journal article – Annual report year: 2004
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.

Introduktion til Operationsanalyse

General information
State: Published
Organisations: Operations Research, Department of Informatics and Mathematical Modeling
Contributors: Larsen, J.
Pages: 4-6
Publication date: 2002
Peer-reviewed: Unknown

Publication information
Journal: ORbit : medlemsblad for Dansk Selskab for Operationsanalyse
Volume: 1
Issue number: 1
ISSN (Print): 1601-8893
Ratings:
Web of Science (2003): Indexed yes
Original language: Danish
URLs:
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
Contributors: Larsen, J.
Publication date: 2002

Staff Scheduling within the Retail Business in Denmark

General information
State: Published
Contributors: Leedgaard, J., Mortensen, K. H., Larsen, A., Larsen, J.
Publication date: 2002

Host publication information
Title of host publication: Proceedings of Nordic MPS 2002
URLs:

Bibliographical note
ISSN 0333-3590
Source: orbit
Source-ID: 58242
Research output: Research › Article in proceedings – Annual report year: 2002

Disruption management

General information
State: Published
Organisations: Operations Research, Department of Informatics and Mathematical Modeling, Department of Transport
Contributors: Clausen, J., Hansen, J., Larsen, J., Larsen, A.
Pages: 40-43
Publication date: 2001
Peer-reviewed: No

Publication information
Journal: OR/MS Today
Volume: 28
ISSN (Print): 1085-1038
Ratings:
ISI indexed (2013): ISI indexed no
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.
Contributors: Løve, M., Sørensen, K. R., Larsen, J., Clausen, J.
Publication date: 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
Contributors: Larsen, J., Clausen, J., Madsen, O. B.
Publication date: 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.

General information
State: Published
Organisations: Operations Research, Department of Informatics and Mathematical Modeling
Contributors: Larsen, J.
Publication date: May 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
Contributors: Larsen, J., Pedersen, I.
Pages: 403-421
Publication date: 1999
Peer-reviewed: Yes

**Publication information**
Journal: Nordic Journal of Computing
Volume: 6
Issue number: 4
ISSN (Print): 1236-6064

Ratings:
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 1
BFI (2015): BFI-level 1
BFI (2014): BFI-level 1
BFI (2013): BFI-level 1
ISI indexed (2013): ISI indexed no
BFI (2012): BFI-level 1
ISI indexed (2012): ISI indexed no
BFI (2011): BFI-level 1
ISI indexed (2011): ISI indexed no
BFI (2010): BFI-level 1
BFI (2009): BFI-level 1
BFI (2008): BFI-level 1

Original language: English
Keywords: auction, performance results, shortest path, parallel computing

URLs:
http://www2.imm.dtu.dk/pubdb/p.php?141
Source: orbit
Source-ID: 199683
Research output: Research - peer-review › Journal article – Annual report year: 1999

**Solutions to the Solomon Test-sets for the Vehicle Routing Problem with Time Windows**

**General information**
State: Published
Organisations: Department of Informatics and Mathematical Modeling
Contributors: Madsen, O. B. G., Larsen, J.
Number of pages: 40
Publication date: 1999

**Publication information**
Original language: English
Source: orbit
Source-ID: 172683
Research output: Research - peer-review › Report – Annual report year: 1999

**Speeding up column generation in VRPTW**

**General information**
State: Published
Organisations: Operations Research, Department of Informatics and Mathematical Modeling
Contributors: Larsen, J., Nielsen, H. B. (ed.)
Pages: 32-33
Publication date: 1999

**Host publication information**
Title of host publication: Third Scandinavian Workshop in Linear Programming
Publisher: Informatics and Mathematical Modelling, Technical University of Denmark, DTU
Source: orbit
Source-ID: 200485
Research output: Research › Article in proceedings – Annual report year: 1999
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.

General information
State: Published
Organisations: Operations Research, Department of Informatics and Mathematical Modeling
Contributors: Larsen, J.
Pages: 23-31
Publication date: 1998
Peer-reviewed: Yes

Publication information
Journal: Ricerca Operativa
Volume: 28
Issue number: 87
Original language: English
Keywords: auction algorithm, performance results, shortest path problem
URLs:
http://www2.imm.dtu.dk/pubdb/p.php?142
Source: orbit
Source-ID: 199685
Research output: Research - peer-review › Journal article – Annual report year: 1998

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.

General information
State: Published
Organisations: Operations Research, Department of Informatics and Mathematical Modeling
Pages: 277-287
Publication date: 1997

Host publication information
Title of host publication: Proceedings of NOAS ’97
Publisher: Informatics and Mathematical Modelling, Technical University of Denmark, DTU
Source: orbit
Source-ID: 200196
Research output: Research - peer-review › Article in proceedings – Annual report year: 1997

Projects:

Integrated optimization of vehicle and driver scheduling in public transport
Govinda Raja Perumal, S. S., PhD Student, Department of Management Engineering
Larsen, J., Main Supervisor, Department of Management Engineering
Lusby, R. M., Supervisor, Department of Management Engineering
Petersen, J. A., Supervisor
Riis, M., Supervisor
Sørensen, K. S., Supervisor
Industrial PhD
01/01/2017 → 31/12/2019
Award relations: Integrated optimization of vehicle and driver scheduling in public transport
Project: PhD
Modeller og Metoder for optimeringsproblemer med kombineret resourceplanlægning og skedulering
Dohn, A. H., PhD Student, Department of Informatics and Mathematical Modeling
Clausen, J., Main Supervisor, Department of Informatics and Mathematical Modeling
Larsen, J., Supervisor, Department of Informatics and Mathematical Modeling
Rønnqvist, M., Examiner
van den Akker, J. M., Examiner
DTU-lønnet stipendie
01/12/2006 → 01/09/2010
Award relations: Modeller og Metoder for optimeringsproblemer med kombineret resourceplanlægning og skedulering
Project: PhD

Udvikling af optimeringsmodeller og løsningsmetoder til ruteplanlægning inden for trampfart
Vilhelmsen, C., PhD Student, Department of Management Engineering
Larsen, J., Main Supervisor, Department of Management Engineering
Pisinger, D., Examiner, Department of Management Engineering
Andersson, H., Examiner
Oliveria, J. F. D., Examiner
Technical University of Denmark
01/01/2010 → 19/12/2014
Award relations: Udvikling af optimeringsmodeller og løsningsmetoder til ruteplanlægning inden for trampfart
Project: PhD

Beslutningsstøtte til genopretning ved uregelmæssigheder i togdrift
Groth, J. J., PhD Student, Department of Management Engineering
Larsen, J., Main Supervisor, Department of Informatics and Mathematical Modeling
Clausen, J., Supervisor, Department of Informatics and Mathematical Modeling
Stidsen, T. J. R., Examiner, Department of Informatics and Mathematical Modeling
Abbink, E. J. W., Examiner
Liebchen, C., Examiner
ErhvervsPhD-ordningen VTU
01/10/2005 → 22/04/2009
Award relations: Beslutningsstøtte til genopretning ved uregelmæssigheder i togdrift
Project: PhD

Managing Cyber Risk and Security in the Global Supply Chain
Sepúlveda Estay, D. A., PhD Student, Department of Management Engineering
Larsen, J., Main Supervisor, Department of Management Engineering
Khan, O., Supervisor, Department of Management Engineering
Oehmen, J., Examiner, Department of Management Engineering
Urciuoli, L., Examiner
Wieland, A., Examiner
Technical University of Denmark
01/11/2014 → 16/04/2018
Award relations: Managing Cyber Risk and Security in the Global Supply Chain
Project: PhD

Dynamic University Timetabling
Lindahl, M., PhD Student, Department of Management Engineering
Stidsen, T. J. R., Main Supervisor, Department of Management Engineering
Herold, M. B., Supervisor
Ho, S. C., Supervisor
Kristiansen, S., Supervisor, Department of Management Engineering
Serensen, M., Supervisor, Department of Management Engineering
Larsen, J., Examiner, Department of Management Engineering
Berghe, G. V., Examiner
Hasle, G., Examiner
Industrial PhD
01/02/2014 → 18/05/2017
Award relations: Dynamic University Timetabling
Project: PhD
Integrated Optimisation of Vehicle Resources in Urban Rail Transport Systems
Thorlacius, P., PhD Student, Department of Management Engineering
Larsen, J., Main Supervisor, Department of Management Engineering
Groth, J. J., Supervisor, Department of Management Engineering
Repke, S., Examiner, Department of Management Engineering
Krasemann, J. T., Examiner
Mannino, C., Examiner
Industrial PhD
01/08/2012 → 23/03/2017
Award relations: Integrated Optimisation of Vehicle Resources in Urban Rail Transport Systems
Project: PhD

Optimal Aircraft Gate Assignment on a Strategic, Tactical and Operational Level
Justesen, T. F., PhD Student, Department of Management Engineering
Larsen, J., Main Supervisor, Department of Management Engineering
Dohn, A. H., Supervisor, Department of Management Engineering
Meincke, D., Supervisor
Larsen, A., Examiner, Department of Transport
Vaaben, B. V., Examiner, Department of Management Engineering
Cohn, A. E. M., Examiner
ErhvervsPhD-ordningen VTU
01/10/2010 → 26/05/2014
Award relations: Optimal Aircraft Gate Assignment on a Strategic, Tactical and Operational Level
Project: PhD

Sustainable Disruption Management
Vaaben, B. V., PhD Student, Department of Management Engineering
Larsen, J., Main Supervisor, Department of Management Engineering
Altus, S., Supervisor
Hansen, J., Supervisor, Department of Informatics and Mathematical Modeling
Larsen, A., Examiner, Department of Transport
Cohn, A. E. M., Examiner
Granberg, T. A., Examiner
ErhvervsPhD-ordningen VTU
01/11/2009 → 04/04/2013
Award relations: Sustainable Disruption Management
Project: PhD

PARALLELIZATION OF THE VEHICLE ROUTING PROBLEM WITH TIME WINDOWS
Larsen, J., PhD Student, Department of Management Engineering
Clausen, J., Main Supervisor, Department of Management Engineering
Forskningsrådsfinansiering
01/01/1998 → 30/09/1999
Award relations: PARALLELIZATION OF THE VEHICLE ROUTING PROBLEM WITH TIME WINDOWS
Project: PhD

Disruption Management i transportsektoren
Wanscher, J., PhD Student, Department of Informatics and Mathematical Modeling
Clausen, J., Main Supervisor, Department of Management Engineering
Larsen, J., Supervisor, Department of Management Engineering
Stidsen, T. J. R., Examiner, Department of Management Engineering
Davidsson, P., Examiner
Liu, R., Examiner
Forskningsrådsfinansiering
01/04/2003 → 01/07/2009
Award relations: Disruption Management i transportsektoren
Project: PhD

Development of a Generic Performance Measurement Model in an Emergency Department
Serup, C. M., PhD Student, Department of Management Engineering
Jacobsen, P., Main Supervisor, Department of Management Engineering
Forberg, J. L., Supervisor
Isenberg Ravn, L., Supervisor  
Larsen, J., Examiner, Department of Management Engineering  
Ceglarek, D. J., Examiner  
Laursen, J. O., Examiner  
1/3 FUU, 1/3 inst 1/3 Andet  
01/04/2012 → 18/06/2015  
Award relations: Development of a Generic Performance Measurement Model in an Emergency Department  
Project: PhD  

Ikke-differentiabel optimering i heltalsprogrammering  
Kallehauge, B., PhD Student, Department of Management Engineering  
Madsen, O. B., Main Supervisor, Department of Planning  
Larsen, J., Supervisor, Department of Management Engineering  
Madsen, K., Supervisor, Department of Applied Mathematics and Computer Science  
Nielsen, O. A., Examiner, Department of Management Engineering  
Lübbecke, M., Examiner  
Pisinger, D., Examiner, Department of Management Engineering  
DTU-lønnet stipendie  
01/08/2000 → 22/05/2006  
Award relations: Ikke-differentiabel optimering i heltalsprogrammering  
Project: PhD  

Robustness in Railway Planning  
Bull, S. H., PhD Student, Department of Management Engineering  
Larsen, J., Main Supervisor, Department of Management Engineering  
Stidsen, T. J. R., Examiner, Department of Management Engineering  
Cacchiani, V., Examiner  
Nielsen, L. K., Examiner  
Technical University of Denmark  
01/05/2013 → 01/09/2016  
Award relations: Robustness in Railway Planning  
Project: PhD  

Models and Algorithms for the Vehicle Routing Problem with Cross Docking  
Wen, M., PhD Student, Department of Transport  
Larsen, J., Main Supervisor, Department of Informatics and Mathematical Modeling  
Claussen, J., Supervisor, Department of Informatics and Mathematical Modeling  
Larsen, A., Examiner, Department of Transport  
Hasle, G., Examiner  
Nielsen, J. B., Examiner, Department of Informatics and Mathematical Modeling  
DTU-lønnet stipendie  
01/02/2006 → 24/03/2010  
Award relations: Models and Algorithms for the Vehicle Routing Problem with Cross Docking  
Project: PhD  

Integretert disponering/genopretning af togdrift  
Haahr, J. T., PhD Student, Department of Management Engineering  
Pisinger, D., Main Supervisor, Department of Management Engineering  
Larsen, J., Supervisor, Department of Management Engineering  
Repke, S., Examiner, Department of Transport  
Huisman, D., Examiner  
Borndörfer, R., Examiner  
Technical University of Denmark  
01/08/2012 → 11/12/2015  
Award relations: Integretert disponering/genopretning af togdrift  
Project: PhD  

Solving Recovery Problems using Optimisations Methods  
Rasmussen, M. S., PhD Student, Department of Management Engineering  
Larsen, J., Main Supervisor, Department of Management Engineering  
Ryan, D., Supervisor  
Larsen, A., Examiner, Department of Transport
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.

Madsen, O. B., Project Manager, Department of Informatics and Mathematical Modeling
Larsen, J., Project Participant, Department of Informatics and Mathematical Modeling
Clausen, J., Project Participant, Department of Informatics and Mathematical Modeling
01/01/1996 → …

Project: Research

Activities:

Tramp ship routing and scheduling with voyage separation requirements
Period: 27 May 2018 → 30 May 2018
Jesper Larsen (Guest lecturer)
Charlotte Vilhelmsen (Guest lecturer)
Richard Martin Lusby (Guest lecturer)
Department of Management Engineering
Management Science
Transport DTU
Operations Research
Degree of recognition: International
Documents:
Abstract-Book-ALL-v2-0

Related event
ROUTE 2018: International Workshop on Vehicle Routing, Intermodal Transportation and Related Areas
27/05/2018 → 30/05/2018
Snekkersten, Denmark
Activity: Talks and presentations › Conference presentations

ODYSSEUS (Event)
Period: 2018
Jesper Larsen (Member)
Department of Management Engineering
Management Science
Transport DTU
Operations Research
Description
Member of Program committee
Degree of recognition: International

Related event
ODYSSEUS
03/06/2018 → 08/06/2018
**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 taxies 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

**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 (Event)  
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 event

The 9th Triennial Symposium on Transportation Analysis  
12/06/2016 → 17/06/2016  
Oranjestad, Aruba  
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

A heuristic and hybrid method for the tank allocation problem in maritime bulk shipping  
Period: 6 Mar 2014  
Charlotte Vilhelmsen (Speaker)  
Jesper Larsen (Other)  
Richard Martin Lusby (Other)

Department of Management Engineering  
Management Science  
Operations Research  
Transport DTU  
Degree of recognition: International

Documents:  
Tank_Allocation_Abstract

Related event

3rd International Symposium on Combinatorial Optimization  
04/03/2014 → 07/03/2014
The Tank Allocation Problem in Bulk Shipping
Period: 27 Sep 2013
Charlotte Vilhelmsen (Speaker)
Jesper Larsen (Other)
Richard Martin Lusby (Other)
Department of Management Engineering
Management Science
Operations Research
Transport DTU
Degree of recognition: International
Documents:
The_Tank_Allocation_Problem

Related event
4th International Conference on Computational Logistics
25/09/2013 → 27/09/2013
Copenhagen, Denmark
Activity: Talks and presentations › Conference presentations

Routing and Scheduling in Tramp Shipping - Integrating Bunker Optimization
Period: 4 Sep 2013
Charlotte Vilhelmsen (Speaker)
Jesper Larsen (Other)
Richard Martin Lusby (Other)
Department of Management Engineering
Management Science
Operations Research
Degree of recognition: International

Related event
OR 2013 - International Conference on Operations Research
03/09/2013 → 06/09/2013
Rotterdam, Netherlands
Activity: Talks and presentations › Conference presentations

EUME Workshop on Metaheuristics (Event)
Period: 2012
Jesper Larsen (Chairman)
Department of Management Engineering
Management Science
Operations Research

Description
Chair of organising committee

Related event
EUME Workshop on Metaheuristics
11/06/2012 → 13/06/2012
Kgs. Lyngby, Denmark
Activity: Membership › Membership of commitees, commissions, boards, councils, associations, organisations, or similar
Triennial Symposium on Transportation Analytics (Event)
Period: 2010 → …
Jesper Larsen (Member)
Department of Management Engineering
Management Science
Transport DTU
Operations Research

Description
Member of program committee
Degree of recognition: International

Related event
Triennial Symposium on Transportation Analytics
20/09/2010 → 25/09/2018
Tromsø, Norway
Activity: Membership › Membership of commitees, commissions, boards, councils, associations, organisations, or similar

Prizes:

Hedorfs Fonds pris for Transportforskning 2017
Jesper Larsen (Recipient)
Department of Management Engineering, Transport DTU, Management Science, Operations Research

Details
Awarded date: 2017
Degree of recognition: National
Prize: Prizes, scholarships, distinctions