Master's thesis project in Operations Research

(Fall 2023)

DTU

Briefly, how to apply for an OR Master-Thesis project

The starting dates for a master-thesis in the Spring are:

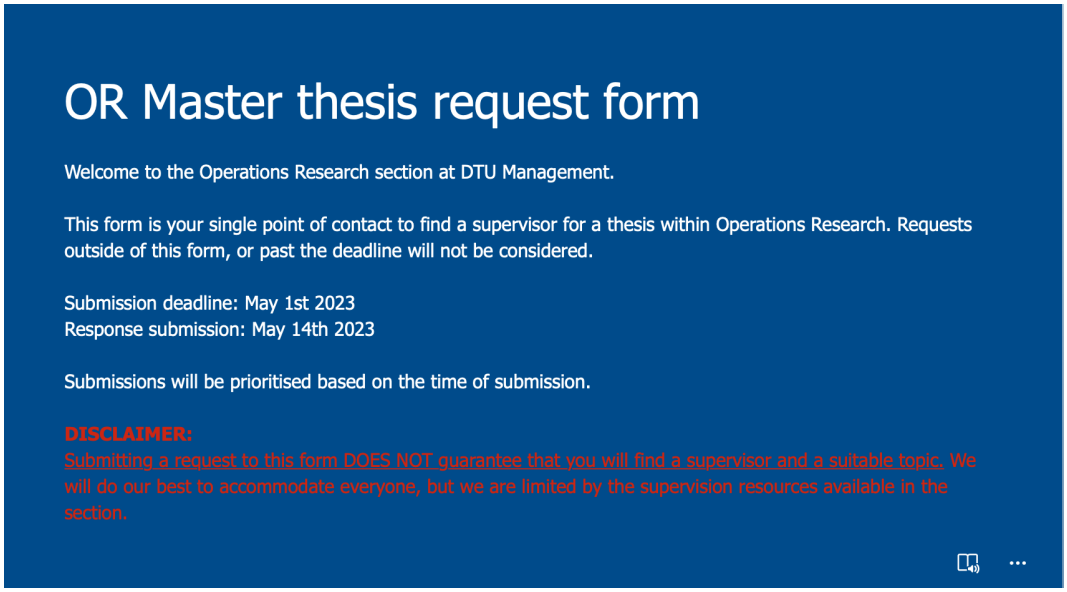
- 31/7 2023
- 21/8 2023

A thesis can be either 30 ECTS points, 32.5 ECTS points or 35 ECTS points and can last for 5 or 6 months, depending on the number of ECTS points.

If you want to write an OR master-thesis in the Spring of 2023 you need to fill in the application form, before 1/5 2023, on the link below:

`https://forms.office.com/e/D3eCVFYuFx`

As stated in the form, picture of first page shown below, we (the OR section) do not guarantee that you will find a supervisor and a suitable topic. We will get back to all applicants, at the latest 14/5, 2023.



Possible OR supervisors

- Associate Prof. Dario Pacino, Email: darpa@dtu.dk
  - Core: Container Terminal Optimization, Maritime Logistics, Heuristics, Modelling
  - Other: City Logistics, Smart City real-time optimization, Constraint Programming
- Prof. David Pisinger, Email: dapi@dtu.dk
  - Core: Maritime Logistics, Liner Shipping Network Design, Railway Optimization, Packing and Loading, Heuristics, Modelling, Network Optimization
  - Other: Health Care, Airport Optimization, Algorithms
- Associate Prof. Evelien van der Hurk, Email: evdh@dtu.dk, Expertise area:
  - Core: (public) transport, network-flow problems, column generation, combinatorial opimization, data & statistics
  - Other: vehicle routing, health-care, supply chain management, simulation, forecasting
- Prof. Jesper Larsen, Email: jesla@dtu.dk
  - Core: transport optimization, Supply chain optimization, integer programming
- Associate Prof. Richard Lusby, Email: rmlu@dtu.dk
  - Core: Decomposition Methods, Integer Programming, Passenger Railway Optimization, Robust Planning
  - Other: Matheuristics, Scheduling, Staff Rostering, Transportation
- Prof Stefan Røpke, Email: ropke@dtu.dk
  - Core: Vehicle routing, integer programming, decomposition methods, meta-heuristics, maritime transport, public transport
  - Other: Collaborative game theory, stochastic optimization, Artificial Intelligence
- Associate Prof. Thomas Stidsen, Email: thst@dtu.dk, Expertise area:
  - Core: Educational timetabling, health-care planning, multi-objective optimization, manpower planning, integer programming
  - Other: financial optimization, energy modelling and optimization

Welcome

In this folder the Section of Operations Research presents a wide range of interesting master's thesis projects. Every year we offer many different projects and at the end of each semester we update this folder and publish it so that you may see what we offer.

As the contents of this folder will show you, we offer a wide variety of different projects. A wide network of industrial contacts enable us to offer you projects in cooperation with companies with many different facets, or you can choose a project with a strong theoretical background.

The typically requirement for starting a master's project in Operations Research is that you have followed an advanced OR course (beyond an introductory course covering linear programming etc.).

At the Technical University of Denmark research in Operations Research is done at the Department of Tehnology, Management and Economics. Here the Section of Operations Resesarch consists of almost 20 researchers, PhD students and research assistants. Further information about the division of Management Science can be found on our homepage at `www.man.dtu.dk`. The department is proud to be member of the Danish Operations Research Society – the largest OR network in Scandinavia.

Apart from the project proposals that are listed in this folder, you are always welcome to contact us if you have a project idea of your own. This folder may serve as a source of inspiration. Your main supervisor must be a permanent faculty member, which at present means Dario Pacino, David Pisinger, Evelien van der Hurk, Jesper Larsen, Richard Lusby, Stefan Røpke, and Thomas Stidsen. In addition our PhD students and PostDocs often take part in the supervision with their fresh ideas and hands on knowledge.

A number of desks in a shared office space are available for master students in Management Science. Requests can be made to your supervisor.

Some of the projects in this folder can also be used as the basis for bachelor projects. If you are interested, ask the designated supervisor of the project.

Projects with Dario Pacino as supervisor

RORO STOWAGE PLANNING

1. SUPERVISOR: Dario Pacino

3. PROJECT BACKGROUND: Under the ROROGREEN research project, DTU, SDU, RUC, and DFDS are working to reduce the emissions of short-sea shipping. At the core of that effort we find the stowage planning problem. In stowage planning we aim at finding the position that each cargo should have on a vessel. The more efficient a stowage planning problem we have, the more emission we are able to reduce.

4. PROJECT ASSIGNMENT: There are several tasks (or project topics) that can be tackled while studying the stowage planning problem. The projects will require the implementation of a mathematical model or the development of metaheuristic method. A project within RORO stowage planning can focus one or more of the following challenges:

- Ensuring vessel stability
- Real-time decision-making (online optimization, reinforcement learning, ...)
- Handling cargo sequencing
- Handling of stochastic cargo arrivals
- Handling of stochastic cargo weights

5. PREREQUISITES: A solid understanding of mathematical modelling and metaheuristics, and a good programming skills.

6. GROUP SIZE: 2-4

RORO CARGO-LOAD PLANNING

1. SUPERVISOR: Dario Pacino

3. PROJECT BACKGROUND: Under the ROROGREEN research project, DTU, SDU, RUC, and DFDS are working to reduce the emissions of short-sea shipping. Traditionally, when a vessel arrives at port all cargo is discharged before new cargo is loaded onto the vessel. DFDS newest vessels are, however, large enough to allow smarted cargo handling operations. A tuck (small truck) that discharges a trailer from the vessel, instead of coming back to empty can load a new trailed. This allows the loading and discharge operations to occur at the same time. Such an operation is called dual-cycling.

4. PROJECT ASSIGNMENT: There can be several tasks (or project topics) that can be tackled while studying RORO dual-cycling operations, and all of them will require the implementation of a mathematical model or the development of metaheuristic methods. A project within RORO dual-cycling can focus one or more of the following challenges:

- Real-time decision making (online optimization, simulation,...)
- Handling uncertain cargo arrival
- Integrating stowage planning

5. PREREQUISITES: A solid understanding of mathematical modelling and metaheuristics, and a good programming skills.

6. GROUP SIZE: 2-4

Container Stowage planning

1. SUPERVISOR: Dario Pacino

3. PROJECT BACKGROUND: Most consumer items that you have at home have likely been transported on a container ship. In nowadays ever growing globalization and the ever present focus on sustainable transport, it is important that we ensure that ocean sailing vessels are efficiently utilized. This means that cargo is arranged such that we best utilize vessel capacity and minimize cargo handling time. This is not an easy task with today's container vessels carrying up to 24.000 containers. Research in this area is still ongoing and no efficient and effective algorithms have yet been identified.

4. PROJECT ASSIGNMENT: In this project you will work on implementing a heuristic for the Master Planning Container Stowage Problem, which is the problem of assigning cargo to portions of the vessel, ensuring stability and minimizing handling time. The project envisions the use of either matheuristic or metaheuristic techniques.

5. PREREQUISITES: Knowledge of operations research methods and programming skills.

6. GROUP SIZE: 2-4

Heuristic for Multi-Port Berth Allocation

1. SUPERVISOR: Dario Pacino

3. PROJECT BACKGROUND: As global trade increases, terminals in ports are being pressured to improve their performance and at the same time being part of the green transition. Research currently run at DTU Management, is studying the possibilities that arise from collaborative planning. In particular, synergies can be exploited when the assignment of a vessels' berth position and their arrival times are planned in collaboration with other terminals. The research project has shown that such a collaboration is beneficial to all parties involved.

4. PROJECT ASSIGNMENT: The above mention research was based on a simplified version of the real problem. Though there is no reason to believe that the results of the analysis are not valid, more work is needed for the algorithms developed to be able to solve real-life problems. In particular, the currently developed methods struggle with scalability and with specific adaptations of the problem definition.

A possibly viable option is the development of a GRASP approach for the problem. Your task in this project would be to design and implement a GRASP approach for the Multi-Port Berth Allocation Problem and compare its results with currently existing method. Other metaheuristic approaches could also be used if this is wished.

5. PREREQUISITES: Knowledge of operations research methods and programming skills.

6. GROUP SIZE: 2-4

Heuristic Solver for IPs using JuMP

1. SUPERVISOR: Dario Pacino

3. PROJECT BACKGROUND: Heuristics and metaheuristics are notoriously hard to implement and maintain, and as a consequence most optimization experts revert to mathematical programming. Unfortunately, mathematical programming is not able to solve all problems. Research on metaheuristics is often limited to either specific application areas or classical problems, and little knowledge is available on model-based approaches.

4. PROJECT ASSIGNMENT: In this project we aim at taking the first steps into the implementation of a general purpose heuristic solver for Integer Programming (IP) models. Your task will be to create a Julia package that can implement a heuristic solver to be used under the JuMP package. In the same way as we have a Gurobi.jl and a CPLEX.jl solver package, your task would be to implement a solver that reads the model from JuMP and runs a general purpose heuristic of your design.

5. PREREQUISITES: Knowledge of operations research methods, programming, and software development skills.

6. GROUP SIZE: 2-4

Projects with Richard Lusby as supervisor

STOCHASTIC LARGE-SCALE MULTICOMMODITY FLOW PROBLEM WITH TRANSIT TIME RESTRICTIONS

1. SUPERVISOR: Richard Lusby

2. PROJECT GROUP: Ignacio Blanco, Klaus Holst (both Maersk)

3. PROJECT BACKGROUND: In liner shipping it is important to continuously evaluate the planned network design of vessels with regards to its ability to transport the expected container transport demand. The evaluation can be performed by solving a large scale multicommodity flow problem with additional constraints e.g. about the delivery time of the container transport. This problem is studied in Karsten et al. 2015. Due to flexibility in contracts, in real life the demand for container transport fluctuates and the actual realization of demand may be different from the planned demand, resulting in overbookings and line congestions. Therefore, it is of great interest to evaluate the robustness of the planned network design when transporting uncertain demand.

4. PROJECT ASSIGNMENT: The master thesis proposal is to explore how to model uncertainty in demand. Designing and implementing mechanisms and solution methods for solving the multicommodity flow problem under demand uncertainty e.g. stochastic programming and robust optimization.

5. PREREQUISITES: Courses: Integer Programming (42114) or Network Optimization, Large Scale Optimization using Decomposition (42136) or Optimization using Metaheuristics (42137), Decisions Under Uncertainty (42586), Good Programming Skills

7. CHARACTERISTICS OF THE ASSIGNMENT: Model development, Decomposition Algorithm Design, Programming

6. GROUP SIZE: 1-2 students.

8. REMARKS: Benchmark paper for liner shipping network design (explain business domain):

Berit D. Brouer, J. Fernando Alvarez, Christian E. M. Plum, David Pisinger, Mikkel M. Sigurd (2013) "A Base Integer Programming Model and Benchmark Suite for Liner-Shipping Network Design." Transportation Science.

Multicommodity flow problem with transit time restrictions (problem to extend):

Christian Vad Karsten, David Pisinger, Stefan Ropke, Berit Dangaard Brouer (2015) "The time constrained multi-commodity network flow problem and its application to liner shipping network design" Transportation Research Part E 76, 122–138.

Include flexible demand contracts in stochastic programming: Guericke, D., Blanco, I., Morales, J.M. et al. A two-phase stochastic programming approach to biomass supply planning for combined heat and power plants. OR Spectrum 42, 863–900 (2020). https://doi.org/10.1007/s00291-020-00593-x

DECOMPOSITION METHODS FOR MAKESPAN MINIMIZATION OF UNRELATED PARALLEL MACHINES

1. SUPERVISOR: Richard Lusby

2. PROJECT GROUP:

3. PROJECT BACKGROUND: This project focuses on the problem of minimizing the makespan of a set of unrelated parallel machines, generally denoted as $R||C_{max}$. Commonly found in manufacturing, the problem requires one to assign a set of tasks to a set of machines in such a way that the makespan, i.e., the time taken to complete all tasks, is minimized. The problem is difficult for a commercial Mixed Integer Linear Programming Solver as the makespan objective induces weak linear programming bounds. In this project, the focus is therefore on solving this problem with decomposition methods and/or heuristics.

4. PROJECT ASSIGNMENT: Investigate the applicability of exact decomposition methods (e.g., Dantzig-Wolfe Decomposition or Lagrangian Relaxation) and/or metaheuristics and compare their performance to existing approaches from the literature using a publicly available benchmark suite of instances.

5. PREREQUISITES: Courses: Integer Programming (42114), Large Scale Optimization using Decomposition (42136) or Optimization using Metaheuristics (42137), Good Programming Skills

7. CHARACTERISTICS OF THE ASSIGNMENT: Model development, Decomposition Algorithm Design, Dynamic Programming

6. GROUP SIZE: 1-2 students.

8. REMARKS:

COMBINING BENDERS DECOMPOSITION AND A DICHOTOMIC SEARCH FOR 2-STAGE STOCHASTIC BI-OBJECTIVE PROGRAMS

1. SUPERVISOR: Richard Lusby

2. PROJECT GROUP:

3. PROJECT BACKGROUND: When formulating an optimization problem it is not uncommon to be able to identify multiple, often conflicting, objective functions. The focus of this project is on bi-objective programs (or problems with two objectives). For such problems the aim is to find a set of efficient solutions, as opposed to a single optimal solution (which is the case for optimization problems with a single objective function). A variety of techniques exists for finding the set of efficient solutions, and one such approach is known as a dichotomic search, which solves a sequence of weighted objective functions that is comprised of the two separate objective functions. Benders decomposition has been widely used to solve two-stage stochastic programs with success. This project will couple Benders decomposition and a dichotomic search to solve two-stage stochastic programs.

4. PROJECT ASSIGNMENT: Devise a Benders Decomposition approach that uses a dichotomic search to identify all extreme non-dominated solutions to a bi-objective two-stage stochastic program. One possible application to be considered is the hierarchical facility location problem under uncertainty. A comparison of the devised algorithm with existing approaches must be provided.

5. PREREQUISITES: Courses: Integer Programming (42114), Large Scale Optimization using Decomposition (42136), Good Programming Skills

7. CHARACTERISTICS OF THE ASSIGNMENT: Model development, Decomposition Algorithm Design, Programming

6. GROUP SIZE: 1-2 students.

INTEGRATING TRAIN TIMETABLING, ROUTING, AND TRACK MAINTENANCE SCHEDULING AT THE CHINESE HIGH SPEED RAILWAY

1. SUPERVISOR: Richard Lusby

2. PROJECT GROUP: Qin Zhang

3. PROJECT BACKGROUND: The Chinese High Speed Railway is the largest high speed railway in the world. To operate this system efficiently it high quality scheduling is of paramount importance. Frequently, track circuits within the network must be removed from operation to undergo maintenance. Such requests are usually received after the timetable (specifying at what times train services will run) has been made. Trains that have been assigned to tracks reserved for maintenance must be rescheduled to allow the maintenance to be performed. The timing of a maintenance task is flexible; it just must be carried out within a specified time window. Trains can be delayed at their origin or at stops along their route. This project will focus on developing an algorithm (exact or heuristic) to simultaneously optimize re-scheduling the timetable, re-routing the trains, and scheduling the maintenance so that undue delay and/or cancellations can be avoided.

4. PROJECT ASSIGNMENT: Design an algorithm (heuristic or exact) for simultaneously determining an adjusted timetable (together with conflict-free trains routes) and timings for a set of maintenance tasks in a subpart of the Chinese High Speed Railway network. Provide a comparison of the algorithm's results with the current best known values.

5. PREREQUISITES: Courses: Integer Programming (42114), Large Scale Optimization using Decomposition (42136), Good Programming Skills

7. CHARACTERISTICS OF THE ASSIGNMENT: Model development, Algorithm design, Programming

6. GROUP SIZE: 1-2 students.

ROLLING STOCK SCHEDULING WITH MAINTENANCE REQUIREMENTS AT THE CHINESE HIGH SPEED RAILWAY

1. SUPERVISOR: Richard Lusby

2. PROJECT GROUP: Qingwei Zhong

3. PROJECT BACKGROUND: The Chinese High Speed Railway is the largest high speed railway in the world. Approximately 2,500 high speed trains are in operation on a daily basis. To ensure the safety of the system, the high speed trains must be regularly maintained (every 24 hours or 5,500 km). This project will focus on developing a column generation approach to find a high quality, maintenance feasible rolling stock schedule for a subpart of the Chinese High Speed Railway. Determining a rolling stock schedule entails finding a sequence of trips for each high speed train will perform (and its composition) that collectively cover all timetabled trips.

4. PROJECT ASSIGNMENT: Implement a column generation approach to solve the rolling stock scheduling problem with maintenance requirements at the Chinese High Speed Railway. Sequences of trips assigned to individual units must adhere to the maintenance restrictions specified. A comparison of the performance of the proposed method with existing methodologies must be included.

5. PREREQUISITES: Courses: Integer Programming (42114), Large Scale Optimization using Decomposition (42136), Good Programming Skills

7. CHARACTERISTICS OF THE ASSIGNMENT: Model development, Decomposition Algorithm Design, Programming

6. GROUP SIZE: 1-2 students.

8. REMARKS: Data provided by the Chinese High Speed Railway

DETECTING GOOD DECOMPOSITIONS FOR THE CAPACITATED LOT SIZING PROBLEM WITH SETUP TIMES

1. SUPERVISOR: Richard Lusby

2. PROJECT GROUP: Stefan Røpke

3. PROJECT BACKGROUND: Dantzig-Wolfe reformulation is a technique that can be used to improve the relaxation bound for mixed integer programs. The approach relies on a specification of so-called blocks. Each block contains a set of variables and constraints that are local to that block. The polyhedra defined by the blocks can be restated in terms of convex combinations of their extreme points, and the resulting reformulation is solved using column generation to improve the model's computational tractability. In ongoing work at DTU, we have developed a tool, known as AUTODEC, for automatically implementing Dantzig Wolfe reformulation. That is, given a mixed integer program and a specification of blocks, AUTODEC will automatically implement Dantzig-Wolfe decomposition. For some problems, in particular, the so-called Capacitated Lot-Sizing Problem with Setup Times, the approach is highly sensitive to the number of blocks specified. In this project, the focus of the project is developing techniqes for – automatically – determining the best number of blocks (and their respective sizes).

4. PROJECT ASSIGNMENT: The purpose of this project is to further automate AUTODEC by investigating techniques for automatically detecting good block structures for the Capacitated Lot-Sizing problem with setup times. Possible directions to explore include machine learning, community algorithms, and hypergraph partitioning.

5. PREREQUISITES: Courses: Integer Programming (42114), Large Scale Optimization using Decomposition (42136), Good Programming Skills

7. CHARACTERISTICS OF THE ASSIGNMENT: Algorithm Design, Programming, Machine Learning

6. GROUP SIZE: 1-2 students.

REMOVING REDUNDANT COLUMNS IN COLUMN GENERATION

1. SUPERVISOR: Richard Lusby

3. PROJECT BACKGROUND: One known downside of using column generation to solve mixed integer programs is that often (many) columns that are not necessary to define any integer solution are generated. Detecting such redundant columns and preventing their generation can have a positive impact on the convergence of column generation, particularly for *time dependent decompositions* (see Lübbecke et al. (2019). The approach proposed by Lübbecke et al. (2019)) adds classical Benders cuts in the subproblems to ensure that redundant columns are not generated. The focus of this thesis is on investigating the performance of the Lübbecke et al. (2019) approach on the capacitated lot-sizing problem with setup times and the temporal knapsack problem.

4. PROJECT ASSIGNMENT: Implement the approach of Lübbecke et al (2019) within AUTODEC, a tool developed at DTU to automatically implement Dantzig Wolfe Decomposition, and investigate the impact of removing redundant columns problem classes like e.g., the temporal knapsack problem and the capacitated lot-sizing problem with setup times. Comparisons to existing state-of-the-art methodologies will be made. A summary of alternative approaches that attempt to generate only columns that define integer solutions is also mandatory.

5. PREREQUISITES: Courses: Integer Programming (42114), Large Scale Optimization using Decomposition (42136), Good Programming Skills

7. CHARACTERISTICS OF THE ASSIGNMENT: Decomposition Algorithm Design, Programming

6. GROUP SIZE: 1-2 students.

8. REMARKS: Lübbecke, M. E., Maher, S. J., and Witt, J., Avoiding redundant columns by adding classical Benders cuts to column generation subproblems (2019).

SOLVING A HIERARCHICAL FACILITY LOCATION & VEHICLE ROUTING PROBLEM

1. SUPERVISOR: Richard Lusby

2. PROJECT GROUP:

3. PROJECT BACKGROUND: Hierarchical facility location problems are concerned with determining the location of facilities in a multi-level network. Typically, the objective is to serve the customers at the lowest level efficiently and effectively. One practical application of the HFLP is in the design of a reverse logistics network. Reverse logistics can be thought of as the opposite of the standard supply chain; products move from the end user back to the manufacturer where they can be properly re-purposed or recycled. Examples of two types of facilities in reverse logistic networks include collection centers and recycling centers. Where to place the different facilities to minimize, among other things, the transportation cost is of crucial importance. Fleets of specific, capacitated vehicles are available in each level of the hierarchy to transport the product moving in each level and require routing. In this thesis the focus is on designing a solution approach to simultaneously solve this hierarchical (facility) location routing problem. As the demand for a particular "customer"in each level can be satisfied by multiple vehicles, each routing problem is essentially a split delivery vehicle routing problem, which is coupled together by the facility placements.

4. PROJECT ASSIGNMENT: Design an implement a meta-heuristic and/or an exact approach to solve the hierarchical location routing problem. Test the methodology on randomly generated instances.

5. PREREQUISITES: Courses: Integer Programming (42114), Large Scale Optimization using Decomposition (42136), Good Programming Skills

7. CHARACTERISTICS OF THE ASSIGNMENT: Model development, Decomposition Algorithm Design, Programming

6. GROUP SIZE: 1-2 students.

BENDERS DECOMPOSITION FOR THE SPLIT DELIVERY VEHICLE ROUTING

1. SUPERVISOR: Richard Lusby

2. PROJECT GROUP:

3. PROJECT BACKGROUND: The so-called split delivery vehicle routing problem (SDVRP) is a variant of the well known vehicle routing problem in which a customer's order can be split across multiple vehicles. State-of-the-art solution approaches for the SDVRP commonly use a relaxed two-index flow formulation. As it is a relaxation, integer solutions must be checked for feasibility and cut away if they are infeasible. Such a Branch-and-cut approach can be implemented as a benders decomposition procedure, where benders/feasibility cuts can be generated from an appropriate subproblem. Determining integer infeasibility of the subproblem can be particularly time consuming. Improvements in relation to this will result in significant improvements to the approach.

4. PROJECT ASSIGNMENT: This thesis will focus on implementing the benders decomposition procedure in Julia/JuMP with cut callbacks and in particular focus on detecting integer infeasibility of the subproblem. The dveloped methodology will be tested on well-known benchmark instances.

5. PREREQUISITES: Courses: Integer Programming (42114), Large Scale Optimization using Decomposition (42136), Good Programming Skills (Julia or C++)

7. CHARACTERISTICS OF THE ASSIGNMENT: Model development, Decomposition Algorithm Design, Programming

6. GROUP SIZE: 1-2 students.

PRODUCTION & SUPPLY CHAIN OPTIMIZATION WITH COLUMN GENERATION

1. SUPERVISOR: Richard Lusby

2. PROJECT GROUP: Bo Vaaben - OpsAnalytics

3. PROJECT BACKGROUND: A large production company has three factories in Europe and distributes approximately 60 different product types to customers all over the world. The company can distribute the products by various modes of transportation. The company would like to optimize their daily plans for which products should be produced at each factory and how the products should be distributed. The problem is consequently an integrated production and supply chain model. A model, which solves this daily, planning problem does already exist and is implemented in OPL.

4. PROJECT ASSIGNMENT: In collaboration with Ops-Analytics the student should reformulate and improve an existing optimization that can be formulated and solved using column generation. To prototype various possible decompositions, AUTODEC (a tool that automatically implements Dantzig-Wolfe Decomposition can be used). The student must identify and implement a decomposition algorithm to solve the problem. Solution quality provided by, not to mention the speed of, the designed algorithm will be compared to the existing model.

5. PREREQUISITES: Courses: Integer Programming (42114), Large Scale Optimization using Decomposition (42136), Good Programming Skills

7. CHARACTERISTICS OF THE ASSIGNMENT: Model development, Decomposition Algorithm Design, Programming

6. GROUP SIZE: 1-2 students.

8. REMARKS: Data will be provided by Ops-Analytics, and the project will be confidential.

THE CLASSIFICATION YARD BLOCK-TO-TRACK ASSIGNMENT PROBLEM

1. SUPERVISOR: Richard Lusby

3. PROJECT BACKGROUND: Classification yards act as large consolidation points in the freight rail industry. The handling of rail cars at such yards is of paramount importance to their efficiency. At a classification yard arriving (or so-called inbound) trains are disassembled and re-grouped/classified into groups of rail cars sharing the same destination. These groups of rail cars are then combined to form new outbound trains, which subsequently leave the yard. How best to sort the rail cars such that the average dwell time in the yard for all rail cars is minimized is an interesting research question and not trivial to answer. A classification yard consists of a number of parallel tracks (each with a certain length) on which cars can be sorted. Which track to assign each rail car is an important subproblem in the handling of rail cars and is the focus of this project.

4. PROJECT ASSIGNMENT: For this project the student(s) will be required to propose mathematical model(s) for the the block-to-track assignment problem, discussing any advantages and/or disadvantages. In addition, implementation of an exact algorithm or a metaheuristic will be required to validate the model.

5. PREREQUISITES: Introduction to Operations Research (42101), Integer Programming (42114), Optimization using meta-heuristics (42137).

6. GROUP SIZE: 1-2 students.

7. CHARACTERISTICS OF THE ASSIGNMENT: Model analysis, meta-heuristic implementation. Good programming skills will be an advantage

8. REMARKS:

THE CARDINALITY CONSTRAINED SHIFT DESIGN PROBLEM WITH MEAL BREAKS

1. SUPERVISOR: Richard Lusby

2. PROJECT GROUP:

3. PROJECT BACKGROUND: 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. In order to make sure a solution to this problem is easily managed in practice, the number of shift types one is allowed to use is bounded by some upper limit (hence *cardinality constrained*, and typically the chosen set must be the same on each day of the planning horizon. This is despite the fact that the demand scenarios for each day are not identical. Finally, it is important to identify when meal breaks should be provided to staff members within each of the shift types as this also impacts the quality of the final solution.

4. PROJECT ASSIGNMENT: For this project the student(s) will be required to formulate the cardinality constrained shift design problem with meal break selection as an optimization problem and implement a solution algorithm (exact and/or heuristic) to solve it.

5. PREREQUISITES: Introduction to Operations Research (42101), Integer Programming (42114), Optimization using meta-heuristics (42137).

6. GROUP SIZE: 1-2

7. CHARACTERISTICS OF THE ASSIGNMENT: Model analysis, meta-heuristic implementation. Good programming skills (C++, Java) will be an advantage

CYCLIC ROSTER CONSTRUCTION

1. SUPERVISOR: Jesper Larsen and Richard Lusby

3. PROJECT BACKGROUND: For large companies efficiently rostering the employees is an extremely important, yet highly challenging problem. The final rosters must usually obey a large set of union rules, consider employee satisfaction, be cyclic in nature, and distribute the workload as evenly as possible across the employees. Staff salaries often constitute the single most expensive resource companies face, and hence optimizing staff utilization can be of significant benefit.

4. PROJECT ASSIGNMENT: This project considers cyclic roster construction for airport security staff. The student must devise an optimization based algorithm for designing rosters (with a cyclicity of 4 weeks) that teams of security officers will work. It is anticipated that the student(s) will devise a column generation procedure to solve this.

5. PREREQUISITES: Courses: Integer Programming (42114), Large Scale Optimization using Decomposition (42136) or Optimization using meta-heuristics (42137), good programming skills

6. GROUP SIZE: 1-2 Students

7. CHARACTERISTICS OF THE ASSIGNMENT: Integer Programming, Column Generation, Staff Rostering, Cyclic Rostering

POWER PLANT PREVENTIVE MAINTENANCE SCHEDULING

1. SUPERVISOR: Richard Lusby

3. PROJECT BACKGROUND: Scheduling power plant preventive maintenance is an important problem for any power company. This problem entails determining when each power plant should be taken "offline" to perform the necessary safety inspections and/or running maintenance. Power plants are essential components of the electricity network and any failures have the potential to be very disruptive. Since power plants cannot produce when taken offline, it is essential that their respective maintenance periods are coordinated as efficiently as possible. Furthermore, the demand for power is stochastic in nature and one must minimize the cost associated with maintaining the power plants while satisfying the demand in a variety of scenarios.

4. PROJECT ASSIGNMENT: The aim of this project is to develop an optimization tool for determining this preventive maintenance scheduling problem. It is expected that the student will implement an exact decomposition based algorithm, or an advanced metaheuristic. Data for this problem is available and the solutions obtained with the developed methodology will be compared to the known benchmarks.

5. PREREQUISITES: Courses: Integer Programming(42114), Large Scale Optimization using Decomposition (42136) or Optimization using meta-heuristics (42137), good programming skills

6. GROUP SIZE: 1-2 Students

7. CHARACTERISTICS OF THE ASSIGNMENT: Integer Programming, Decomposition, Maintenance, Scheduling

PHARMACEUTICAL MANUFACTURING

1. SUPERVISOR: Richard Lusby

2. PROJECT GROUP: Jesper Larsen

3. PROJECT BACKGROUND: The production of a pharmaceutical product can be a complicated process. Typically, it is synthesized in batches from quantities of raw material in such a way that the greatest quantity of the final product, having a pre-specified potency, can be manufactured. Complicating issues include the deterioration of the quality of the raw material over time (which ultimately results in a final product with a lower potency), target batch sizes for the final product, and mixing restrictions on the input raw material. Decisions on which raw materials to mix, and when and where to produce the final products must be made. The unnecessary wastage of raw material should be avoided; however, supplementary production can be possible in some cases.

4. PROJECT ASSIGNMENT: Devise a mathematical programming model, along with a solution method, to optimize the manufacturing process of a pharmaceutical product. Typically, the objective of the problem is to maximize the quantity of the final product produced; however, here consideration will also be given to the sensitivity of the solution to changes in input parameters. In addition, an extensive review of Operations Research methods applied to similar problems must be completed. For the solution method, exact and/or heuristic methods may be developed.

5. PREREQUISITES: Integer Programming (42114), Optimization using meta-heuristics (42137), good programming skills

6. GROUP SIZE: 1-2 students

7. CHARACTERISTICS OF THE ASSIGNMENT: Modelling, algorithm design, literature study

CONSTRAINED QUADRATIC ASSIGNMENT FOR FACILITY LAYOUT DECISION

1. SUPERVISOR: Richard Lusby

2. PROJECT GROUP: Jesper Larsen, Troels Martin Range

3. PROJECT BACKGROUND: A recurrent issue when making changes in a hospital is where different functions have to be positioned such that the total distance traveled is minimized. A number of positions are typically available and functions can be placed at these positions. The hospital of South West Jutland is focusing on minimizing the nonproductive travel distance of employees (which corresponds to walking between functions). A number of workshops is being held where (among other aspects) repositioning of functions is being discussed. In practice, a point observation (following one or more employees on a given day) of the number of trips between functions is conducted and the repositioning is based on this observation. The distance between positions can be measured in meters or number of steps. The problem under consideration corresponds to a quadratic assignment problem where potential side constraints may be added e.g., the distance between certain facilities should not be greater than a given amount or if one function is in a specific position then another cannot be close by.

4. PROJECT ASSIGNMENT: The focus of this project is to formulate and solve the above problem using Operations Research techniques, ultimately providing a tool that can possibly benchmark proposed solutions.

5. PREREQUISITES: Courses:Integer Programming (42114), Optimization using meta-heuristics (42137), good programming skills

6. GROUP SIZE: 1-2 students

7. CHARACTERISTICS OF THE ASSIGNMENT: Modelling, algorithm design

8. REMARKS: Courses: Integer Programming (42114), Optimization using meta-heuristics (42137), good programming skills

6. GROUP SIZE: 1-2 students

7. CHARACTERISTICS OF THE ASSIGNMENT: Modelling, algorithm design

Projects with Jesper Larsen as supervisor

INTEGRATED TRAIN DRIVER AND STATION DRIVER DUTY PLANNING

1. SUPERVISOR: Jesper Larsen

2. PROJECT GROUP: NN (DSB)

3. PROJECT BACKGROUND: At DSB we have two types of drivers. There are the classic train drivers who drive the commercial departures on the main tracks and there are the station drivers who only drive within the station on local tracks. The train drivers are allowed to drive on some tracks within a station but not necessarily all and the station drivers are not allowed to drive on any main tracks out side a station. The station drivers are normally attached to a specific station whereas the train drivers vary wrt. what part of the rail network they are allowed to drive. The duties of any driver are composed by task derived from the rolling stock schedule. The Rolling stock schedule is the plan for the train sets defining what train types are covering which departures and how many sets must cover each departure. The train sets have various needs of refueling, emptying of toilets, cleaning inside and out etc. that is carried out in the stations. Between having these needs handled and covering specific departures the train sets may be parked in the station.

4. PROJECT ASSIGNMENT: Today duties of drivers are planned completely separately and the decision of what type of driver covers a task is made in advanced. Formulate and implement an integrated model of making duties for respectively train drivers and station drivers based on the tasks in the rolling stock schedule. The objective is to answer the question of how many drivers of each type must be located on each crew depot.

5. PREREQUISITES: Operations Research courses equivalent to (42114) Integer Programming and (42132) Large Scale Optimization using decomposition. Good programming skills.

6. GROUP SIZE: 1-2 persons.

8. REMARKS: The student will have to sign a cooperation agreement. Publishing must be agreed with supervisor.

SCHEDULING TRAIN CLEANING

1. PROJECT SUPERVISOR: Jesper Larsen

2. PROJECT GROUP: NN (DSB)

3. PROJECT BACKGROUND: An important part of good passenger service is to maintain a nice and clean environment for the passengers. In the trains that is the responsibility of the operator, that is, DSB. Although the cleaning is done by an external contractor the schedules for the cleaning is made by DSB and then forwarded to the contractor. At DSB there are three different types of cleaning based on how much time is available and how thorough the cleaning should be. Cleaning can only be performed at designated stations on the route. The process of developing the schedules for the cleaning is currently being done manually with no or very little system support.

4. ASSIGNMENT: The aim of this thesis is to develop, implement and present a method for automatically determining the cleaning schedules. The schedules must comply with the rules and regulations of DSB and must be able to minimize cost and/or other appropriate measures. The project also allows to develop new ideas for producing the schedule and compare to real-life schedules from DSB.

5. QUALIFICATIONS: At least Introduction to Operations Research and Integer Programming. Programming experience is an advantage.

6. GROUP SIZE: 1-2 persons

7. CHARACTERISTICS OF THE ASSIGNMENT: Real-life problem solving, modelling and solving. Heuristics.

8. REMARKS: The student will have to sign a cooperation agreement. Publishing must be agreed with supervisor.

MODELLING OF ENERGY PRODUCTION

1. PROJECT SUPERVISOR: Jesper Larsen, Richard Lusby

2. PROJECT GROUP: Jonas Sigtenbjerggaard (Ørsted)

3. PROJECT BACKGROUND: The Analytics and Optimization department in Bioenergy at Ørsted offer a practical master thesis project, concerning the modelling of power and heat production at the Danish power plants.

The Analytics and Optimization department provides decision support tools of high importance to the Trading Floor which trades power and heat 24/7 365 produced at our power plants with possible regulations every hour. One of the key application, Octopus, is built around a large mathematical model. The model is a MIQCP solved in two steps, first as a MIP where the quadratic constraints are linearized, then step two as a QCP where the solution from step 1 are used to fix all integer variables. The MIP model is solved as a generalized model using CPLEX as solver. Step 2 is quickly solved, however the MIP can take from a few seconds to several minutes – depending on the calculation type, season and general input data.

It is critical that the calculations are as quick as possible. Looking into a future with tighter deadlines and more flexible energy system, hence more regulations, the calculations can no longer take several minutes. Also when moving away from large power plants to smaller but many more different assets, such as hydrogen electrolyzer and heat pumps the number of choices increases, hence there is a risk of larger and more complex models.

4. ASSIGNMENT: This project aims at investigating the existing model, finding a more suitable specialized algorithm to use and hopefully implement a prototype. The specialized algorithm can for example be decomposition.

5. QUALIFICATIONS: At least three courses in Operations Research. Programming experience is an advantage. The solver is wrapped in C# code so experience with Visual Studio and C# is an advantage.

6. GROUP SIZE: At least 2 persons

7. CHARACTERISTICS OF THE ASSIGNMENT: Real-life problem solving, and you have to love decomposition techniques and implementation. Heuristics.

PATIENT ADMISSION SCHEDULING

1. SUPERVISOR: Jesper Larsen

3. PROJECT BACKGROUND: Newly admitted patients need a free bed that satisfies both the personal preferences (single, twin room, or a ward) as well as the medical needs of the patient located in the department that is specialized in treating the clinical picture. The assignment of patients to beds is often carried out by a central admission office that individually contacts every appropriate department a few days before the effective admission of the patient. Other hospitals organize the admission of patients without a central admission office, leaving admission responsibility with the departments. In the latter case, a lack of overview of the departments may result in under occupancy. Patients may be refused in one department while free suitable beds are available in another department. Generally speaking patients can be divided in two groups: inpatients and outpatients. Inpatients spend several days or nights in a hospital, whereas the admission of outpatients is expressed in hours. This project will concentrate inpatients only. Inpatients can further be divided in three groups: emergency, elective and admitted patients. Emergency patients are hard to schedule, since by definition they have no appointment with the physician and arrive at random. Elective inpatients are waiting for an admission date. This means that an admission office can determine when to admit them. Such patients allow the hospital to improve its occupancy rate as they can be assigned to the most appropriate period. In this paper however, we simplify the problem by assuming that the patients' admission dates are known before. The physician who advised the patient to be admitted to the hospital, diagnosed the patient's disease which is associated with a default (average) length-of-stay.

4. PROJECT ASSIGNMENT: Present methods for solving the patient admission scheduling problem all rely on metaheuristics which often does not exploit problem structure very good. This project should devise and implement a solution approach based on mathematical programming. It is foreseen that the initial parts of the project will consist in developing mathematical models and the second part of implementing and testing the most promising model.

5. PREREQUISITES: (42101) Introduction to Operations Research, and a background at least equivalent to (42114) Integer Programming is necessary. Knowledge about column generation would be an advantage. Good programming skills.

6. GROUP SIZE: 1-2 students

8. REMARKS: For more details and test problems go to `http://allserv.kahosl.be/~peter/pas/`.

LINE PLANNING FOR F&R

1. SUPERVISOR: Jesper Larsen

2. PROJECT GROUP: NN (DSB)

3. PROJECT BACKGROUND: The current schedule for DSB F&R consists of train systems which share fleet hand have different stopping patterns (Intercity fast, intercity and regional). The line concept is not used as such, which may be due to the bottle neck that Fynen represents. The fleet consists of 5 different types that are currently in use (IC3, IC4, DD, IR4, OUT, Vectron (locomotive)).

4. PROJECT ASSIGNMENT: To find possible lines to be driven by DSB which resemble the current schedule while minimizing costs and maintaining a certain level of quality for the passengers Furthermore, the study should include an analysis on the amount of fleet needed. The goal is to investigate how to re-use the current fleet and find the number of vehicles missing to perform the optimal line planning. For mor information please refer to the attached images Special considerations:

- The study should also consider the location of the workshops in regard to the usage of the fleet to avoid empty travels.
- The creation of a line for peak hour
- Nowadays, when travelling long distances the passengers do not need to change train in order to complete their journey. This concept is very important for measuring the plan in terms of quality for the passengers.
- No line pool is given

5. PREREQUISITES: (42101) Introduction to Operations Research, and a background at least equivalent to (42114) Integer Programming is necessary. Knowledge about heuristics would be an advantage. Good programming skills.

6. GROUP SIZE: 1-2 students.

8. REMARKS: The student will have to sign a cooperation agreement. Publishing must be agreed with supervisor.

VRPs WITH INTERDEPENDENT ORDERS

1. SUPERVISOR: Jesper Larsen

2. PROJECT GROUP: Kristian Hauge (AMCS)

3. PROJECT BACKGROUND: In the world of waste collection, it is not always only about collection and waste. Specifically for bulk waste in skip containers, the container itself is often part of the optimisation. This includes delivering, emptying, and sometimes returning the containers to their owners. A container that is not owned by the customer can be delivered to another customer who has requested the same type of container, instead of simply being returned to a depot. This can save a lot of driving to and from depots. However, because of this, and because a vehicle can only carry a handful of full containers at a time, a route often consists of stops that are tightly connected to each other and even depend on each other. Scheduling of terminal stops and choice of terminals can also depend on and/or affect the orders on a route.

When there is a lot of interdependence between stops, an algorithm that is well suited for optimising other types of VRPs may not be well suited for this problem.

4. PROJECT ASSIGNMENT: Given real-life data, the task is to design and implement an algorithm for solving the described VRP.

5. PREREQUISITES: (42101) Introduction to Operations Research, and a background at least equivalent to (42114) Integer Programming is necessary. Knowledge about column generation would be an advantage. Good programming skills.

6. GROUP SIZE: 1-2 students.

8. REMARKS: AMCS is a software company specialising in fleet management products. Transport optimisation, mathematical modelling and prototype implementation.

CYCLING ROSTERING

1. PROJECT SUPERVISOR: Jesper Larsen

2. PROJECT GROUP: NN (Qampo)

3. PROJECT BACKGROUND: This project is based on a case of cyclic rostering that Qampo is solving for a customer in the rail industry. Cyclic rosters tend to follow a predefined work cycle designed to give ideal balance between daily work and rest. Cyclic rosters are used to assure both equality among workers and the best service quality.

Today Qampo solves the problem using a MIP model, but they would like to explore the use of metaheuristics.

4. ASSIGNMENT: Given is a set of Rosters, each with minimum and maximum number of weeks A set of shifts, each with a start and end time in a generic week (e.g. start = Monday 8:00 and end = Monday 16:00). A set of business rules to be observed such as:

- Minimum resting time between shifts
- At least two resting days per week
- Minimum and maximum working time per week

The aim is to determine the number of weeks to be used in each roster, and assign each shift to a week in one of the rosters. The goal is to minimize the number of unassigned shifts and minimize the number of weeks with working time more than the minimum or less than the maximum bounds.

5. QUALIFICATIONS: At least Introduction to Operations Research and Integer Programming. Programming experience and the metaheuristic course is an advantage.

6. GROUP SIZE: 2 persons

7. CHARACTERISTICS OF THE ASSIGNMENT: Real-life problem solving, modelling and solving. (Meta) heuristics.

VERY LARGE TSP WITH GEOGRAPHICAL CONSTRAINTS

1. SUPERVISOR: Jesper Larsen

2. PROJECT GROUP: Kristian Hauge (AMCS)

3. PROJECT BACKGROUND: In a high-density VRP such as residential waste collection or letter distribution, most addresses in a city or region need to be visited. At AMCS we are experimenting with a model where all stops are placed in one long "master sequence". This master sequence is in some ways just modelled as a very long route. But it is way too long to be used as it is. However, real operational routes are created from this master sequence in a process that involves little to no optimisation. Routes can then be created with varying lengths and duration depending on demand and resources on a given day. This adds robustness and flexibility to a master plan.

To maintain some sort of order, the master sequence should to some extent finish an area before entering a new area. This also makes it feasible/practical to divide the master sequence across different days when routes are created. The definition of an "area" is not strict.

4. PROJECT ASSIGNMENT: Given real-life data, the task is to design and implement an algorithm that can build a master sequence that displays the requested geographical features. It should be able to handle tens of thousands of stops.

5. PREREQUISITES: Courses in Operations Research and knowledge of metaheuristics. Good programming skills are an advantage.

6. GROUP SIZE: 1-2 students.

8. REMARKS: AMCS is a software company specialising in fleet management products. Transport optimisation, mathematical modelling and prototype implementation.

SEQUENCE BUILDING WITH NARROW TIME WINDOWS

1. SUPERVISOR: Jesper Larsen

2. PROJECT GROUP: Kristian Hauge (AMCS)

3. PROJECT BACKGROUND: Given a set of orders, a route/sequence needs to be built with the following constraints:

- A small portion of the orders (< 10%) will have time windows. Time windows can be as narrow as 30 minutes.
- A feasible solution is not guaranteed due to time windows and order locations, so soft time windows are allowed – there will be an increasing cost the larger a time window violation.
- A good solution must be produced as fast as possible.

A route consists of around 100-200 orders.

4. PROJECT ASSIGNMENT: Given real life data, implement an algorithm that can build an order sequence give the listed constraints.

5. PREREQUISITES: Courses in Operations Research and knowledge of metaheuristics. Good programming skills are an advantage.

6. GROUP SIZE: 1-2 students.

8. REMARKS: AMCS is a software company specialising in fleet management products. Transport optimisation, mathematical modelling and prototype implementation.

LARGE SCALE RESIDENTIAL VRP

1. SUPERVISOR: Jesper Larsen

2. PROJECT GROUP: Kristian Hauge (AMCS)

3. PROJECT BACKGROUND: Residential VRPs involve most addresses in a town or city. The number of orders can therefore be very high, think 10000 to 100000. Even though these problems have few or no restrictions, they are still challenging to solve due to their size.

4. PROJECT ASSIGNMENT: Given real life data, implement an algorithm for solving large VRPs. Ideas for extensions/focus areas:

- With no restrictions, routes are expected to not overlap. Seek to reduce/avoid this.
- Routes that are neighbours are often expected to be separated along the most logical lines. These lines are usually easy to identify or compare for the human eye and are often related to features such as highways, rivers, or "gaps" between orders such as parks or industrial areas.
- Having a distance matrix available is useful, but for very large VRPs, memory is precious. How many distances do we need to calculate and cache?

5. PREREQUISITES: Courses in Operations Research and knowledge of metaheuristics. Good programming skills are an advantage.

6. GROUP SIZE: 1-2 students.

8. REMARKS: AMCS is a software company specialising in fleet management products. Transport optimisation, mathematical modelling and prototype implementation.

BUILDING NICE-LOOKING ORDER SEQUENCES FOR SIDE-LOADERS

1. SUPERVISOR: Jesper Larsen

2. PROJECT GROUP: Kristian Hauge (AMCS)

3. PROJECT BACKGROUND: A side-loader is a term used for a vehicle, such as a garbage truck, that can only service orders on one side of the road. A normal road in a residential neighbourhood that is serviced by a side-loader must therefore be visited twice, once in each direction. At the same time, U-turns are not allowed on the route. The vehicle is too large and the roads not wide enough. Determining a good sequence for the orders on a route usually focuses on KPIs such as the total driving time or the total distance covered. But the shortest or fastest route is not always the best. It is sometimes also expected that a vehicle finishes the area it started to service before it moves on to the next. And this can be a challenge for side-loaders due to their limited options for movement and service. A side-loader route can start in one area and then "wander off" to different areas before returning much later to service the remaining orders in the first area.

4. PROJECT ASSIGNMENT: Given real life data, implement an algorithm for building an order sequence for a side-loader route. The algorithm should consider the typical concrete KPIs, total driving time and/or route length, but also the desire that routes are "pretty" and do not have too many "left over" orders in an area; orders that are not serviced until much later.

5. PREREQUISITES: Courses in Operations Research and knowledge of metaheuristics. Good programming skills are an advantage.

6. GROUP SIZE: 1-2 students.

8. REMARKS: AMCS is a software company specialising in fleet management products. Transport optimisation, mathematical modelling and prototype implementation.

USING COLUMN GENERARION FOR THE ELECTRIC BUS SCHEDULING PROBLEM

1. SUPERVISOR: Jesper Larsen

2. PROJECT GROUP: NN (Qampo)

3. PROJECT BACKGROUND: Given a set of timetabled trips and recharging stations, the electric vehicle scheduling problem (E-VSP) is concerned with finding a vehicle schedule that covers the trips and satisfies the driving range and recharging requirements of electric buses while minimizing operational cost. Currently, a column generation algorithm in combination with variable fixing strategies is used to find feasible solutions. For some of the real-life instances, we have observed the following behaviours of column generation: 1) the linear programming objective does not change for several iterations, 2) dual fluctuations seem to be quite large. Overall, we see that the convergence of the column generation algorithm has been quite slow for some cases.

4. PROJECT ASSIGNMENT: One would have to implement column generation for the E-VSP and the aim of the project could be to explore acceleration techniques such as dual stabilization or other techniques to speed up the column generation progress. We can provide some real-life instances for the project. An instance would contain a set of trips, set of deadheads, set of vehicle types, set of nodes (including where recharging stations are present).

5. PREREQUISITES: Courses in Operations Research and knowledge of column generation and Dantzig-Wolfe decomposition. Knowledge of other decomposition approaches would be an advantage. Strong programming skills are an advantage.

6. GROUP SIZE: 1-2 students.

SOLUTION APPROACHES TO THE SOLAR FARM CABLE LAYOUT PROBLEM

1. SUPERVISOR: Jesper Larsen

3. PROJECT BACKGROUND: Solar energy is a renewable and sustainable energy, which gets more and more important in times where humanity aims to reduce the usage of fossil fuels. Photovoltaic modules are used to convert sun light into electricity. Often this is done in large solar farms. We model a solar farm as layered graph, where the power generated by the strings (several connected photovoltaic modules) needs to be conducted throughthe layers of the graph. For the connection of two vertices there are different typesof cables with different capacities and costs. The problem is now to find a cable layout with minimal costs, which does not violate cable or vertex capacities.

4. PROJECT ASSIGNMENT: Current methods still have problems solving large solar farm cases. Here MILPs are not able to solve the problems in 24 hours. Therefore this project has a focus on developing new matheuristics or new optimal methods based on alternative decomposition techniques.

5. PREREQUISITES: Courses in Operations Research and potentially knowledge of metaheuristics. Good programming skills are an advantage.

6. GROUP SIZE: 1-2 students.

8. REMARKS: The project is based on the MSc thesis of Dominik Stampa entitled "Theory and Algorithms of the SolarFarm Cable Layout Problem". With the thesis also follows instances and data.

Projects with Evelien van der Hurk as supervisor

LIMITING COVID-19 OUTBREAK

1. SUPERVISOR: Evelien van der Hurk, Rowan Hoogervorst

2. PROJECT BACKGROUND: Although we hope we have (the majority) of the COVID-19 pandemic behind us, it remains an interesting question what are the best policies to limit the outbreak of such a disease. Many will remember the close down of many events, and the requests to also limit the personal contacts one has. The most popular models to inform these policies are based on homogeneous mixing of population, where simply a reduction in the number of contacts a person makes leads to a reduction in disease spread. However, research has shown that people are more likely to interact with a smaller number of contacts consisting of e.g. friends, relatives, and colleagues. Therefore these standard models tend to overestimate the risks of contacts between people – especially in settings where the same group of people meet over time. If we would have better models, could we allow more contacts between people to actually reach the same effect of limiting an infectious disease?

In this project you will focus on modelling the spread of an infectious disease like COVID-19 in a social network. Most research in the spread of a virus in networks are considering static networks, but as most social contacts are varying over time, dynamic networks are more interesting. You will investigate how a (set of) contact limitation policies could curb the spread of the disease. Ideally, one would want few(er) limitations. The modeling of such limitations can be seen as decomposing a graph. When limitation policies are introduced, the decomposition is uncertain as we cannot know how the graph is decomposed, e.g., if there is a limit on social gatherings for 10 people, we cannot know which 10 people different individuals meet up with at social gatherings.

The main objective of the project is to investigate the policies specifically aimed at limiting contacts in people's private social network, acknowledging the uncertainty of the way these measures will decompose a given graph.

3. PROJECT ASSIGNMENT: We have seen that decomposing graphs by minimizing distinct contacts between people has a positive effect when we can organize these decompositions perfectly. However, in social settings we do not have this full control.

What are the impacts of recommending a limit on the total number of contacts a day, versus the creation of "bubbles"of different types? How does this interact with how "open"the society is in general? What is the effecitiveness of these measures given that they do not provide a precise control over the decomposition of the graph?

There have been several standard graph-types developed to describe social networks in general, e.g.: Erdos-Renyi Model, the Watts-Strogatz Model, and the Barabasi-Albert Model. The thesis could focus on how different ways of recommended contact limitations would influence the spread of the disease in these different types of graphs. One could for example use classification of nodes in terms of e.g. vitality and centrality, e.g., node vitality, closeness centrality and betweenness centrality to formulate "worst case"and "best case"outcomes of the recommendations.

The thesis could also investigate other measurements that are not mentioned here, or approximations of the before mentioned measurements.

Finally, an alternative direction is focusing on how to limit spread of covid in transportation, when one would be allowed to assign passengers a specific boarding location for the vehicle.

4. PREREQUISITES: Operations research methods, combinatorics, graph theory, simulation, programming skills (Java, C++, C#, Julia).

5. GROUP SIZE: 2–3 students

SEAMLESS SUSTAINABLE EVERYDAY URBAN MOBILITY

1. SUPERVISOR: Evelien van der Hurk

2. PROJECT BACKGROUND: Even if everyone would be driving electric cars tomorrow, we would not reach the CO2 targets to limit global warming to $1.5 - -2$ degrees. Therefore we need to increase the share of other forms of sustainable transportation: walking, biking, and public transportation. Often, these modes are connected in a door-to-door journey, and therefore providing a smooth integration between these different modes could increase their share.

Typically, there would be a limited budget available to upgrade parts of the system. The question is then which parts of the system should be upgraded to attract the majority of passengers. This question can be investigated on many different levels:

- Network level: which lines should be upgraded to BRT/light rail to provide a faster more reliable service?
- Station level: which stations should be upgraded to provide more attractive entrance and exit points to the system? Which stations could profit most from being connected to other modes of shared transportation like shared cars or bikes?
- Street level: which streets could best be upgraded (for walking or biking) to increase their share in general and increase the catchment areas of public transport stations?

3. PROJECT ASSIGNMENT: All the above listed problems are closely related to well-known optimization models in OR, such as (quadratic) knapsack problems, set covering problems, or problems related to network optimization and multi-commodity flow problems. Your thesis could either focus on a) investigating solution methods for special cases of these problems, or b) investigating these problems based on real-life data and a case from the Copenhagen Region. Either way, your thesis would contribute to the international EASIER project where together with Norwegian, Swedish and German partners we aim to increase the share of sustainable transportation modes.

4. PREREQUISITES:
- Programming skills (e.g. Julia lang, Python, Java, ...)
- Introduction to Operations Research: as well as a second course (equivalent to) (42113) Networks or Integer Programming.

6. GROUP SIZE: 2–3

7. CHARACTERISTICS OF THE ASSIGNMENT: optimization, public transport

ON DEMAND LINE PLANNING (FOR AN UBER BUS)

1. SUPERVISOR: Evelien van der Hurk

2. PROJECT GROUP: Theoretical work based on the concept of on-demand minibusses, such as the Uber-bus

3. PROJECT BACKGROUND: You are probably familiar with the concept of shared transport options like Uber and Lyx. These are focussed on sharing private vehicles in a taxi-service kind of way. A different form of public transport is that of on-demand mini-busses: Uber is introducing this in Egypt, while there exists already many informal systems for this in other countries like South Africa.

The research questions here are: first if all, if you have such an on-demand system, what is the best way to operate it? And secondly, given an idea about the demand over time, what would be the best lines to operate?

4. PROJECT ASSIGNMENT: You will employ simulation and/or optimization techniques to try to investigate at least one of the above research questions.

5. PREREQUISITES:

- Programming skills (e.g. Julia lang, Python, Java, ...)
- Introduction to Operations Research: as well as a second course (equivalent to) (42113) Networks or Integer Programming.
- Knowledge about (meta/math) heuristics, decomposition methods, and/or column generation would be an advantage – as well as knowledge on vehicle routing.

6. GROUP SIZE: 2–3

7. CHARACTERISTICS OF THE ASSIGNMENT: optimization, public transport, vehicle routing, line planning

Improving bus transfers

1. SUPERVISOR: Evelien van der Hurk

2. PROJECT GROUP: Practical project: can we improve bus transfers in practice? In collaboration with Movia

3. PROJECT BACKGROUND: One of our previous studies showed that we can improve transfer times of busses without increasing vehicle costs. However, this has never been implemented at Movia. The question you will investigate is: could we actually create something that reduces transfer times at Movia?

4. PROJECT ASSIGNMENT: There are two main issues with the approach in the previous paper:

- The approach used an (expensive) solver in a matheuristic
- The approach ignored any uncertainty in the driving times of the busses

In your project you will investigate at least one of the two above questions. Real data from Movia could be obtained, or we could work with the data from the previous study. The first task would be aimed at testing simpler heuristics in order to see if they could still obtain a benefit in transfer times. The second would be focused on somehow taking uncertainty into account, either in an evaluation setting (by programming a simulation), through data analysis (of operational data, to signal problems in delays), or from a pro-active optimization perspective to (re)distribute slack.

You can read more about our previous study here:
`https://www.sciencedirect.com/science/article/pii/S0191261517304915`

5. PREREQUISITES:

- Programming skills (e.g. Julia lang, Python, Java, ...)
- Introduction to Operations Research: as well as a second course (equivalent to) (42113) Networks or Integer Programming.
- Knowledge about (meta/math) heuristics, decomposition methods, and/or column generation would be an advantage – as well as knowledge on vehicle routing.

6. GROUP SIZE: 2–3

7. CHARACTERISTICS OF THE ASSIGNMENT: optimization, public transport, vehicle routing, line planning

Projects with Stefan Røpke as supervisor

SCHEDULING MAJOR COMPONENT EXCHANGE AT OFFSHORE WIND FARMS

1. SUPERVISOR: Stefan Røpke, Michael Berliner Pedersen (Ørsted), Simon Spoorendonk (Flowty)

2. PROJECT BACKGROUND: In the operation of offshore wind farms the exchange of major components like gear boxes or blades requires jack-up vessels. These are usually leased for a period of time to perform maintenance at one or multiple wind farms. The planning of the major exchange component tasks is done for 3-6 months at a time. The planning is affected by factors such as weather conditions, predicted turbine failures, and contractual terms of the jack-up vessels. The project is carried out in collaboration with Ørsted A/S and Flowty ApS. Ørsted is a global offshore wind farm operator. Flowty offers a library of algorithms tailored for network optimization.

3. PROJECT ASSIGNMENT: The purpose of the project is to use network optimization to schedule the maintenance tasks for the given time horizon. With offset in existing planning models a mathematical model must be built that captures aspects like the seasonal weather impact on task times and the stochasticity in the predicted turbine failures. A solution approach should be implemented, e.g., as i) a meta-heuristic or ii) a column generation algorithm (exact or math-heuristic).

4. PREREQUISITES: Programming skills (Julia, Python, C++), good knowledge of network optimization and concepts like column generation, dynamic programming.

5. GROUP SIZE: 1-2

6. CHARACTERISTICS OF THE ASSIGNMENT: exact methods, heuristics, framework

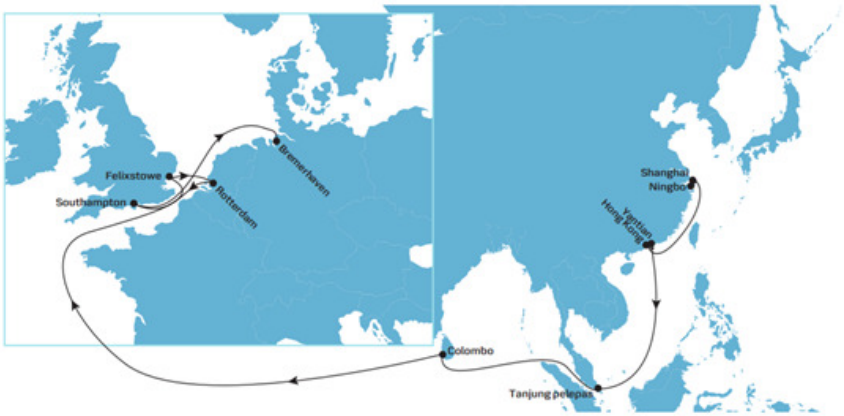
7. REMARKS: The exact same project is also offered with David Pisinger as DTU supervisor.

LINER SHIPPING NETWORK DESIGN

1. SUPERVISOR: Stefan Røpke

2. PROJECT BACKGROUND: Many of the goods that we buy in shops have been produced far from Denmark and are transported here using container ships. Container ships travel along fixed routes and several ships share the same routes such that the ports on the routes recieve a weekly visit by a container ship. The routes combined constitute a transportation network that allow cargoes to be shipped between two ports that are not connected by any route. This is possible by transshipping cargoes between different routes one or more times during the voyage.

The set of routes that a container liner company chooses to operate has a large impact on its business: The network decides the cost of operations; it decides which cargoes that can be transported as well as the level of service provided to the customers (shipping times).



3. PROJECT ASSIGNMENT: Design and implement a solution method for the liner shipping network design problem. Test the approach on instances from LinerLib data set.

4. PREREQUISITES: Some programming experience in e.g. C, C#, C++, Java or Julia. At least one of the courses 42114 Integer programming, 42137 Optimization using metaheuristics, 42115 Network Optimization, 42132 Large Scale Optimization using decomposition.

5. GROUP SIZE: 1-2

6. CHARACTERISTICS OF THE ASSIGNMENT: Maritime optimization, integer programming, transportation

7. REMARKS: David Pisinger and Pierre Pinson offers a similar project.

AUTOMATIC DANTZIG WOLFE DECOMPOSITION

1. SUPERVISOR: Stefan Røpke and Richard Lusby

2. PROJECT BACKGROUND: At DTU we are currently doing research on how to automatize Dantzig-Wolfe decomposition. A goal of the research project is to develop methods that solves mixed integer programming programs using Dantzig-Wolfe decomposition and column generation entirely without any user involvement. In the long run, such methods could be embedded into solvers like CPLEX or Gurobi and improve their performance on certain problem classes. We would like to invite MSc students to collaborate on this project.

3. PROJECT ASSIGNMENT: Many projects can be envisioned within the Automatic Dantzig Wolfe Decomposition research project. Some examples are:

- Test the developed methods on new problem classes. Is it possible to find new classes of problems where the approach has potential?
- A very time consuming part of the algorithm is to solve the sub-problems during column generation. Is it possible to devise fast heuristic to speed up the sub-problem solve time?
- At the moment the algorithm is very generic, but it is possible to specialize the algorithm to a specific problem classes. It could be interesting to work on a specialized version of the algorithm for solving important problem types.
- Often it is possible to aggregate identical sub-problems when applying Dantzig-Wolfe decomposition. This is not currently supported by the algorithm and would be a valuable addition.

4. PREREQUISITES: Programming experience, experience with column generation and Dantzig-Wolfe decomposition, for example through the courses 42136 Large Scale Optimization using Decomposition.

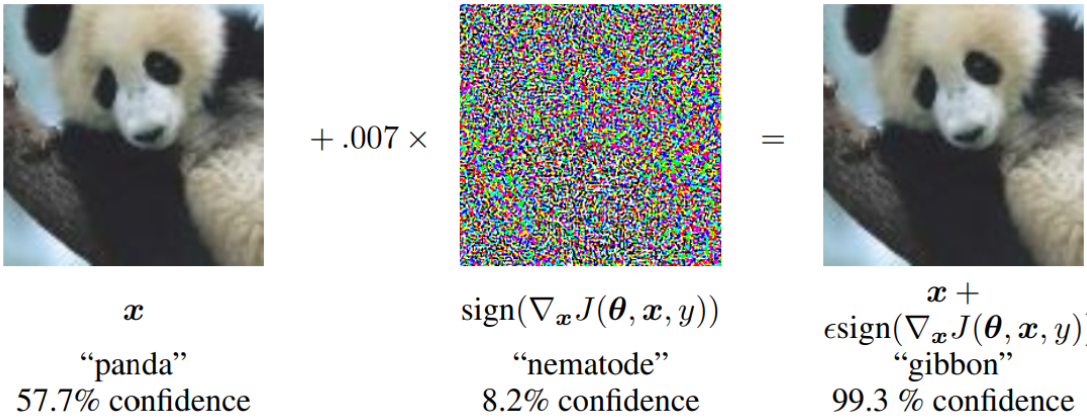
5. GROUP SIZE: 1-2 students

6. CHARACTERISTICS OF THE ASSIGNMENT: Dantzig-Wolfe decomposition, column generation, integer programming

VERIFICATION OF NEURAL NETWORKS

1. SUPERVISOR: Stefan Røpke and Richard Lusby

2. PROJECT BACKGROUND: In the past decade we have seen neural networks being used with great success in a number of applications. However, there are some concerns about using neural networks when it comes to decisions that potentially could mean life and death to a person. An example of such an application is the use of neural networks in self-driving cars. Part of the concern is fueled by the presence of "adversarial examples" for neural networks. Adversarial examples are inputs to the neural network that are blatantly being mis-classified by the neural network. Figure 1 shows an example of an adversarial example. On the left we have a picture of a panda which also is being classified as an image of a panda with good confidence by an image recognition neural network. We then apply a small modification of the picture which is shown in the center of the figure (notice that the change is exaggerated in the center image, the real change is just 0.7% of what is shown) and the result is the picture on the right which to the human eye looks almost identical to the left image. The neural network however now thinks that the image shows a gibbon and it is even extremely confident in this classification.



Figur 1: Example of an adversarial example. The figure is from *Goodfellow, Ian J., Jonathon Shlens, and Christian Szegedy. "Explaining and harnessing adversarial examples."arXiv preprint arXiv:1412.6572 (2014).*

One way to verify that a trained neural network is robust to adversarial attacks involves solving optimization problems like linear programming problems or mixed integer programming problems. The basic idea is that we would like to verify with certainty that there are no adversarial examples in a "neighborhood" around a certain input example. The "neighborhood" defines how large modifications we allow to make to the input example and we detect an adversarial example if the output changes dramatically inside this neighborhood. Verifying that there are no adversarial examples amounts to maximizing an objective function that measures output change and checking that the value of the objective function is limited for all inputs within the neighborhood of the input example.

3. PROJECT ASSIGNMENT:

- Develop a mathematical optimization model that verifies that a simple neural network is robust against adversarial attacks

After that one could

- Develop faster methods for solving the optimization problem (faster than just solving it with a standard generic MIP or LP solver)
- Experiment with the definition of neighborhood or the definition of the objective function in the optimization problem
- Conclude if the implemented model/method is useful for verifying that a neural network is robust against adversarial attacks.

4. PREREQUISITES:

- Introduction to operations research
- Introduction to Machine Learning and Data Mining

5. GROUP SIZE: 1-2 students

6. CHARACTERISTICS OF THE ASSIGNMENT: Neural networks, Linear programming, Integer Programming.

HEURISTICS FOR MIXED INTEGER CONIC PROBLEMS

1. SUPERVISOR: Stefan Røpke

3. PROJECT BACKGROUND: Even though an mixed-integer optimization problem is solved with a branch & bound algorithm then a heuristic for finding good feasible solutions is useful. An interesting project is to generalize the heuristics from linear to conic case. In particular the efficient generalization of the feasibility pump heuristic would be interesting. The project is to be carried out in collaboration with MOSEK ApS.

4. PROJECT ASSIGNMENT: Get to know second-order cone programming and some of the standard heuristics for mixed integer linear programming. Develop and implement a heuristic for mixed integer conic problems.

5. PREREQUISITES: Programming skills. Some flair for mathematics.

6. GROUP SIZE: 1-2

7. CHARACTERISTICS OF THE ASSIGNMENT: non-linear programming, integer programming, heuristics.

8. REMARKS: Relevant literature

- Lobo, Vandeberghe, Boyd, Lebret, Applications of second-Order cone programming, Linear algebra and its applications 284 (1998) 193-228
- Alizadeh, Goldfarb, Second-order cone programming, Mathematical programming 95 (2003) 3-51.
- Fischetti, Glover, Lodi, The feasibility pump, Mathematical programming 104 (2005), 91-104

SOLVING REAL LIFE VEHICLE ROUTING PROBLEMS

1. SUPERVISOR: Stefan Røpke

3. PROJECT BACKGROUND: Real life vehicle routing problems typically contains more complicated constraints or objective functions compared to the standard problems studied in the literature. In this project we will contact the company AMCS who specializes in vehicle routing software and the exact topic of the project will be decided by the problems the company currently are working on.

4. PROJECT ASSIGNMENT: Develop heuristics or exact methods for solving real life vehicle routing problems.

5. PREREQUISITES: Mandatory:

- Programming experience.

Nice to have, but not mandatory:

- Integer programming (42114).
- Optimization using metaheuristics (42137)
- Transport optimization (42117)

6. GROUP SIZE: 1-2

7. CHARACTERISTICS OF THE ASSIGNMENT: Vehicle routing, heuristics, exact methods.

COMPONENTS OF A MIXED INTEGER LINEAR PROGRAMMING SOLVER

1. SUPERVISOR: Stefan Røpke

3. PROJECT BACKGROUND: Writing a mixed integer linear programming solver that can compete with state of the art solvers require many software components like separation routines for known cutting planes, heuristics for finding feasible solutions, presolvers for simplifying the problem and methods for selecting which variables to branch on, to name a few. Writing just one of these components can be an interesting challenge in itself.

4. PROJECT ASSIGNMENT: The purpose of this project is to work on a selected component and test the impact of that component. It could for example be implementing a new separation routine for cutting planes or a new heuristic for finding feasible solutions. The project is to be carried out in collaboration with MOSEK ApS.

5. PREREQUISITES: Programming skills (C or C++). Good knowledge of integer programming.

6. GROUP SIZE: 1-2

7. CHARACTERISTICS OF THE ASSIGNMENT: Integer programming, exact methods, heuristics, cutting planes.

STOCHASTIC VEHICLE ROUTING PROBLEMS

1. SUPERVISOR: Stefan Røpke

3. PROJECT BACKGROUND: Classical vehicle routing problems like the capacitated vehicle routing problem (CVRP) or the vehicle routing problem with time windows (VRPTW) assume that all data are known in advance. This assumption is obviously not always satisfied in practice. It is therefore interesting to study variants of the vehicle routing problem where part of the input data is given as random variables with known distribution, commonly know as stochastic vehicle routing problems. Examples are the vehicle routing problem with stochastic demands or the vehicle routing problem with stochastic travel times.

4. PROJECT ASSIGNMENT: Select a stochastic vehicle routing problem and design/implement a solution method for it.

5. PREREQUISITES: Programming skills. Relevant courses (none of them are a strict requirement): 42114 Integer Programming. 42115 Network Optimization. 42137 Optimization using metaheuristics. 42117 Transport optimization

6. GROUP SIZE: 1-2

7. CHARACTERISTICS OF THE ASSIGNMENT: Stochastic programming, vehicle routing problem, heuristics, exact methods.

8. REMARKS: Relevant literature (one example):

CH Christiansen, J Lysgaard, A branch-and-price algorithm for the capacitated vehicle routing problem with stochastic demands, Operations Research Letters 35 (2007), 773–781.

OPTIMAL OPERATION OF BATTERIES IN THE ELECTRICITY MARKET

1. SUPERVISORS: Nina Lange, Stefan Røpke

2. PROJECT GROUP: Possible industry collaborator

3. PROJECT BACKGROUND: The decarbonisation of the energy industry is a main target of most nations. Fossil fuels are being phased out as the main primary energy sources and replaced by renewable energy from wind or solar power. The increasing share of energy from variable sources into the electricity production makes the balancing of large-scale electric systems more difficult and costly, but the decreasing costs of storage technologies have made battery energy storage systems an appealing solution for a number of applications, notably on the balancing markets. In the United Kingdom, the electricity market was recently reformed to authorise stand-alone batteries to participate in the balancing mechanism.

4. PROJECT ASSIGNMENT: The goal of the project is to make algorithms for optimal charging and discharging of a battery in the UK electricity market. The emphasis of the project is up to the student(s). More focus can be put on modelling of electricity prices as input to the optimization algorithm or focus can be put on designing optimal algorithms based on a simpler price forecast.

5. PREREQUISITES: Core courses in Financial Modelling is a plus, if the focus is on the modelling of the electricity markets. Core courses in optimization is a plus, if the focus is on the charge/discharge algorithm. The project contains programming in Julia, Python, R or Matlab.

6. GROUP SIZE: 1 or 2 persons.

7. CHARACTERISTICS OF THE ASSIGNMENT: Optimization, batteries, electricity markets, balancing markets

OPERATIONS RESEARCH AND BIODIVERSITY PRESERVATION

1. SUPERVISORS: Stefan Røpke

2. PROJECT GROUP: Professor, Niels Strange from Department of Food and Resource Economics (IFRO) at University of Copenhagen

3. PROJECT BACKGROUND: All over the world species are facing extinction due to human activities. One way to combat this extinction is to protect land areas that are rich in biological life in order to prevent destruction of the habitats of the endangered species. Unfortunately, it is not possible to protect all the areas that biologist would like to conserve (it is simply to costly compared to the money available for such activities). Operations research techniques can therefore be used to help select the most valuable areas to protect given the budget available for buying land. For more information, see, for example: Strange, Niels, Jette B. Jacobsen, Bo J. Thorsen, and Peter Tarp. "Value for money: protecting endangered species on Danish heathland." Environmental management 40, no. 5 (2007): 761-774

4. PROJECT ASSIGNMENT:

- Read existing work on biodiversity preservation using OR techniques.
- Select a case and gather data.
- Develop a model that selects areas to protect based on a given budget. The model can take stochasticity into account.

5. PREREQUISITES: Modelling experience. Integer programming (42114). Experience with stochastic programming is a plus.

6. GROUP SIZE: 1 or 2 persons.

7. CHARACTERISTICS OF THE ASSIGNMENT: Biodiveristy, modelling, stochasticity.

CO_2 NEUTRAL CONTAINER SHIPPING

1. SUPERVISORS: Stefan Røpke

3. PROJECT BACKGROUND: The transport sector is facing huge changes in the next decades. Eventually it will have to change its energy source from fossil fuels to renewable energy. In this project we like to focus on how the container shipping industry could switch to renewable energy. One possibility is to switch to fuels such as hydrogen or ammonia. Hydrogen can be produced from water and ammonia can be produced from hydrogen and nitrogen with nitrogen being abundant in the atmosphere. In both cases electricity is needed in the production of the fuels and that electricity could for example come from wind turbines or other renewable sources.

4. PROJECT ASSIGNMENT: Assume that the hydrogen is chosen as the fuel of future container ships. The project could look into where the hydrogen should be produced and where container ships should be fueled in the most efficient way. A straightforward approach would be to produce the hydrogen next to the most busy harbors around the globe using wind turbines, but it may more beneficial to produce the hydrogen elsewhere (where wind conditions may be better or where other sources of renewable energy exists) and transport the hydrogen to the harbors where the fuel is needed. Therefore a mathematical model should be developed that chooses the production locations for hydrogen and plans transport to harbors where the fuel is needed, if necessary

5. PREREQUISITES: Some programming experience, modelling experience. Integer programming (42114)

6. GROUP SIZE: 1 or 2 persons.

7. CHARACTERISTICS OF THE ASSIGNMENT: Liner shipping, CO_2 neutral fuels, Transport optimization.

CO_2 NEUTRAL TRUCK TRANSPORT

1. SUPERVISORS: Stefan Røpke

3. PROJECT BACKGROUND: Currently, it is not clear how heavy road based transport (trucks) should be fueled in a future where fossil fuels are no longer used in the transportation sector. For personal cars it seems like battery powered electric cars is a possible way forward. However, this solution does not seem suitable for heavy trucks given the current technology. The weight and volume of the needed batteries would simply be impractical. Instead two main directions are being investigated: 1) either trucks could be powered using fuels produced using electricity (electrofuels), an example could be hydrogen, 2) or the trucks could be supplied with electricity while driving, this could be using overhead wires, power rails in the roads or wireless charging built into roads. Electricity would (of course) need to be generated using renewable sources for all of these alternatives to be CO_2 neutral.

4. PROJECT ASSIGNMENT: In this project we will look at the operations research problems that arise with a system where trucks are supplied with electricity while driving. One of the two following assignments should can be addressed in the project:

1. Building up infrastructure for charging-while-driving is going to be extremely costly no matter what technology one chooses (overhead wires/power rails/wireless charging). On could imagine a system where trucks can be charged while driving on highways and need a (low capacity) battery for the trips outside the highway network. However, is this the smartest placement of charging infrastructure? Perhaps one would obtain a better coverage of Denmark by only providing charging-while-driving one some highway segments and then also provide charging-while-driving on some segments outside the highway network. In this assignment you should develop a model that selects the road-segments where charging-while-driving is installed. The segments should be selected to maximize the number of trips that can be carried out by electric trucks given a certain budget on how much infrastructure to install.
2. In the second assignment one should assume that charging-while-driving already has been installed on selected road segments and this is given as input. One should then model and solve a vehicle routing problem for electric trucks that can recharge while driving on the powered road segments. The vehicle routing problem addresses how to distribute goods from a central depot to a number of customers using a fleet of trucks. The output of the vehicle routing problem is a delivery route for each truck. Given that the trucks only have a limited range when driving outside the powered road segments this creates new constraints in the vehicle routing problem and means that solutions, potentially would look different from a solution using diesel based trucks.

5. PREREQUISITES: Programming experience, Some of the courses 42114 Integer programming, 42137 Optimization using metaheuristics and 42117 Transport optimization

6. GROUP SIZE: 1 or 2 persons.

7. CHARACTERISTICS OF THE ASSIGNMENT: Road based transportation, CO_2 neutral fuels, Transport optimization.

Projects with Thomas Stidsen as supervisor

Rheumatism treatment planning

1. SUPERVISOR: Thomas Stidsen (DTU)

3. PROJECT BACKGROUND: The Danish organisation Gigtforeningen, is an organisation which treats patienst for rheumatism. Given a specialized hospital which offers different treatments to patients, the planning problem is to select which treatment of the patient to perform when, given the different resources.

4. PROJECT ASSIGNMENT: The project assignment is first to analyze the planning problem, then to model the problem with one or more MIP models and finally to solve the problem.

5. PREREQUISITES: Mathematical Programming with Modelling Software (42112) and at least two other Operations Research course

5. GROUP SIZE: 1-2

Manpower planning at Planday

1. SUPERVISOR: Sune Rastad Bahn (Planday), Simon Kløve Christensen (Planday), Thomas Stidsen (DTU)

3. PROJECT BACKGROUND: Planday is a Danish IT company, which sells a Software As A Service (SAAS) IT system for staff management and planning. The system is aimed at shift based companies like restaurants, cafés, bars etc. but also within healthcare, e.g. Covid testing. Together with DTU, Planday has developed a solution for automatic manpower planning, i.e. for assigning employees, to the shifts for the coming period, usually the next month.

4. PROJECT ASSIGNMENT: The current version of the automatic manpower planning tool needs to be extended to include: Including supplements in the costs of the shift work, better handling of multiple objectives and an analysis tool of to help the manager analyze the type of labor employed and compare it to the needs.

5. PREREQUISITES: Motivation to work on and learn about a practical problem; experience with mathematical modelling and associated languages, i.e. Julia/JUMP.

5. GROUP SIZE: 1-2

TOOL CONSTRAINED SCHEDULING

1. SUPERVISOR: Thomas Stidsen

3. PROJECT BACKGROUND: The Danish company NetHire, supports all kind of tools used by companies running projects on many sites. Companies can rent tools from one of many NetHire storages, they can store their own tools there and possibly let others rent their tools.

4. PROJECT ASSIGNMENT: Assume a company, e.g. in pluming, has number of plummers working on a number of different projects. Each project has a number of required operations and for each operation a number of different tools are necessary. Since some of the tools are rather expensive, they have to be shared. This project is done in collaboration between DTU and NetHire, a Danish company specialized in supplying tools to Danish companies. The idea is to optimize the schedule of the projects to evaluate how many tools should be bought and how much project time could be saved by buying more tools. When buying, new tools, it also becomes possible to rent out the tools to other plummers.

5. PREREQUISITES: Mathematical Programming with Modelling Software (42112) and at least two other Operations Research course

6. GROUP SIZE: 1-2 persons, preferable 2.

EXAM ROOM ALLOCATION AT DTU

1. SUPERVISOR: Jette Kolby Laub Kristiansen & Thomas Stidsen

3. PROJECT BACKGROUND: Every semester DTU plans the written exams in a large number of rooms. Help the DTU planners to do it optimally !

4. PROJECT ASSIGNMENT: Given a set of written exams, a set of students, select the rooms and timeslots for the exams. Notice, the dates for the exams are given, but the time of day and room needs to be decided.

5. PREREQUISITES: Mathematical Programming with Modelling Software (42112) and at least two other Operations Research course

6. GROUP SIZE: 1-2 persons.

TIMETABLING AT DTU

1. SUPERVISOR: Jette Kolby Laub Kristiansen & Thomas Stidsen

3. PROJECT BACKGROUND: Currently, the DTU timetable is static, i.e. courses are given in the timeslot every semester. Hence, currently, DTU only has to assign rooms to the lectures and exercises. If it was allowed to actually move some of the courses to new timeslots, better room utilization could be achieved.

4. PROJECT ASSIGNMENT: Given the data for the courses for a semester, create an optimized timetable. First fix the timeslots, but then investigate what could be achieved regarding better timetabling. Could evening teaching be avoided ? Can use of flipped classroom for certain courses be utilized in the timetable.

5. PREREQUISITES: Mathematical Programming with Modelling Software (42112) and at least two other Operations Research course

6. GROUP SIZE: 1-2 persons, preferable 2.

MAINTENANCE PLANNING AT TOTAL

1. SUPERVISOR: Kristoffer Vandrup Sigsgaard (MEK) & Thomas Stidsen (MAN)

3. PROJECT BACKGROUND: Total currently operates all oil and gas production in the Danish part of the North Sea. Running these oil-platforms is a complex and costly operation. In particular, maintenance of the platforms is costly, being responsible for app. 40 % of the operating costs. Planning when and what to maintain is complex, because it involves both planned repairs, urgent repairs, limitations on the crew which is needed for the repairs etc. All in all, this creates a very hard planning (optimization) problem.

4. PROJECT ASSIGNMENT: Currently a PhD project at DTU has created a MIP model, in Julia, for the maintenance planning problem. This basis can be extended into both improved MIP models and improved solution models. The project is open to whether to focus on model improvements or optimization improvements with e.g. math-heuristics.

5. PREREQUISITES: Introduction to Operations Research (42101), Mathematical Programming with Modelling Software (42112) and at least one other Operations Research course, e.g. Large Scale Optimization using Decomposition (42136) or Optimization using metaheuristics (42137)

6. GROUP SIZE: 1-2 persons, preferable 2.

OPTIMAL DECISION TREES

1. SUPERVISOR: Thomas Stidsen

3. PROJECT BACKGROUND: Decision trees is a classical approach to clustering, which has been used for many practical problems for decades. Recently, Prof. Dimitris Bertsimas has suggested that this approach can be improved. In this project we will attempt to implement a new approach where decision trees are created using MIP models and optimal decision trees are created.

4. PROJECT ASSIGNMENT: Use MIP models to create optimal decision trees

5. PREREQUISITES: Introduction to Operations Research (42101), Mathematical Programming with Modelling Software (42112). Some knowledge of statistics is required.

6. GROUP SIZE: 1-2 persons.

Mathematical Programming Clustering

1. SUPERVISOR: Thomas Stidsen

3. PROJECT BACKGROUND: Clustering algorithms has for decades been performed using various heuristic algorithms. In this project the job is to apply mathematical programming (Mixed Integer Programming), so to get exact solutions to the clustering problem.

4. PROJECT ASSIGNMENT: The project is to implement new clustering methods using mixed integer programming and compare the performance with the classical clustering algorihtms.

5. PREREQUISITES: Introduction to Operations Research (42101), Mathematical Programming with Modelling Software (42112), programming experience in Julia/JUMP

6. GROUP SIZE: 1-2 persons.

LINEAR REGRESSION DONE RIGHT

1. SUPERVISOR: Thomas Stidsen

3. PROJECT BACKGROUND: The classical approach to Linear Regression usually involves the Lasso algorithm. Recently, Prof. Dimitris Bertsimas has suggested that this approach can be improved. In this project we will attempt to implement his approach and compare it to the Lasso approach. This should lead to a quantification of the two approaches.

4. PROJECT ASSIGNMENT: Solve Linear Regression using Quadradic MIP.

5. PREREQUISITES: Introduction to Operations Research (42101), Mathematical Programming with Modelling Software (42112). Programming experience is a big plus and so is knowledge of the Lasso algorithm

6. GROUP SIZE: 1-2 persons.

Projects with David Pisinger as supervisor

Optimizing labor ordering and berth scheduling for liner vessels

1. SUPERVISOR: David Pisinger, David F. Koza

2. PROJECT BACKGROUND: When container vessels berth at a port to load or unload containers, the cargo carrier needs to book cranes and gangs (that operate the cranes) in advance. The more cranes/gangs are booked, the higher is the productivity (number of moved containers per hour) and the earlier the vessel can leave the port again. Gangs work in shifts that may have different costs depending on the time or weekday. Many other restrictions, as e.g. limited berth availability windows or tidal restrictions, may apply. The time a vessel spends at a port also affects the subsequent sailings and port calls; the faster a vessel finishes operations at a port, the more time is left to sail to the next port and to finish operations at the next port and vice versa. Due to these interdependencies, the planning problem becomes quite complex. The project is carried out together with Maersk Line planners that face these problems on a weekly basis.

3. PROJECT ASSIGNMENT: Describe the resulting vessel berth scheduling and gang optimization problem and examine related literature. Formulate and implement mathematical models to solve the problem and possible extensions. Generate a set of good solutions that can be presented to planners. Analyse the results and derive decision rules to support planners.

Data for actual gang optimization problems will be provided by Maersk Line. Good results may therefore have an actual impact.

4. PREREQUISITES: Motivation to work on and learn about a practical problem; experience with mathematical modelling and associated languages (e.g. CPLEX or Gurobi); fluency in English (as communication with Maersk planners will be in English); programming skills are of advantage.

5. GROUP SIZE: 1-2

6. CHARACTERISTICS OF THE ASSIGNMENT: Liner shipping, scheduling, mathematical modeling, applied optimization

Efficient algorithms for cargo routing in liner shipping networks

1. SUPERVISOR: David Pisinger, David F. Koza

2. PROJECT BACKGROUND: The liner shipping network design problem is a very hard combinatorial optimization problem and subject of ongoing research. The challenge is to construct a network of liner services that operate on cyclic routes, and to route containers through this network such that revenues minus cost are maximized. The majority of solution approaches, including the most promising ones, require to solve a very large number of cargo routing problems as intermediate and reoccurring steps. More efficient algorithms for the cargo routing problem therefore have the potential to significantly improve the performance of network design algorithms as well.

The cargo routing problem consists of finding a path from an origin port to a destination port through a very large network, while respecting constraints as e.g. transit time limits. The cargo routing problem is a shortest path problem with resource constraints (SPPRC).

The goal of this thesis is to investigate how the existing algorithms can be improved, or to develop new approaches. Possible directions of research include the implementation and testing of alternative algorithms (e.g. the A*-algorithm, heuristics) or improved preprocessing techniques.

3. PROJECT ASSIGNMENT: Implement and test different exact or heuristic algorithms and/or preprocessing techniques for the cargo routing problem. Developed algorithms can be tested and evaluated within a solution framework for liner shipping network design, written in C++ and developed at the OR group.

4. PREREQUISITES: Interest in algorithms and their implementation; good programming skills, ideally C++ (as our framework and existing methods are coded in C++); Mandatory courses: 42115 Network Optimization

5. GROUP SIZE: 1-2

6. CHARACTERISTICS OF THE ASSIGNMENT: Cargo routing, resource constrained shortest path problem, liner shipping network design, graph based algorithms

Algorithms for the design of liner services in liner shipping networks

1. SUPERVISOR: David Pisinger, David F. Koza

2. PROJECT BACKGROUND: The liner shipping network design problem is a very hard combinatorial optimization problem and subject of ongoing research. The challenge is to construct a network of liner services that operate on cyclic routes, and to route containers through this network such that revenues minus costs are maximized. The majority of solution approaches imposes only very few restrictions on the design of liner shipping services; in practice, however, network planners have to consider various factors and trade-offs when designing a liner service. Network planners would, for example, try to limit the duration of a service, as shorter services can be adjusted more easily and are easier to cope with in case of delays or disruptions. Another example is the rotation design: in practice, services that call a particular port more than twice are very rare.

Imposing additional restrictions on the service design makes the problem of generating liner services more difficult. Early in the project we will discuss practically relevant restrictions with Maersk planners. The goals are to investigate how these can be modeled, to develop tailored solution algorithms to solve the service design problem efficiently, and to analyze how those additional restrictions affect network design and cost.

3. PROJECT ASSIGNMENT: Construct a mathematical model for the liner service design problem with additional side constraints. Develop and implement heuristic or exact solution algorithms (e.g. dynamic programming based algorithms) to solve the problem. You will have access to a solution framework for liner shipping network design, written in C++ and developed at the OR group, and we would aim at embedding and testing your developed methods within this framework.

4. PREREQUISITES: Good programming skills, ideally C++ (as our framework and existing methods are coded in C++); Mandatory courses: '42115 Network Optimization'.

5. GROUP SIZE: 1-2

6. CHARACTERISTICS OF THE ASSIGNMENT: Liner shipping network design, graph based algorithms

Limiting COVID-19 outbreak by network decomposition

1. SUPERVISOR: David Pisinger

2. PROJECT BACKGROUND: The COVID-19 pandemic caused many countries to lock down large parts of society by establishing different limitation policies as a mean to decrease the spread of the virus. People are working from home, cultural event are cancelled and people can only meet up in small gatherings, meaning that the contacts between individuals have significantly dropped. The limitation policies are evaluated based on population based simulations. As many limitation policies are limiting the contact between people it makes sense to look at the spread of the virus in social networks. Most research in the spread of a virus in networks are considering static networks, but as most social contacts are varying over time, dynamic networks are more interesting. Many limitation policies can be seen as decomposing the graph. When limitation policies are introduced, the decomposition is uncertain as we cannot know how the graph is decomposed, e.g., if there is a limit on social gatherings for 10 people, we cannot know which 10 people different individuals meet up with at social gatherings. Some places we can have impact on how the graph is decomposed, this could be schools, universities or work places, and these are the cases we are considering. The main objective of the project is to investigate the best way to decompose a given graph with a given set of restrictions.

3. PROJECT ASSIGNMENT: We have seen that decomposing graphs by minimizing distinct contacts between people, has a positive effect, but research show that there are other interesting measurements to look at when predicting the spread of a virus in a network. Such measurements include vitality and centrality, e.g., node vitality, closeness centrality and betweenness centrality. Common for these measurements is that the shortest paths between every pair of nodes need to be calculated. While the shortest path problem can be efficiently solved (even every pair of shortest paths), these problems need to be solved many times when using these measurements for decomposing social networks. The thesis could focus on how to efficiently use these measurements when decomposing social networks, and which of the measurements have the biggest impact on limiting the spread of COVID-19, either using exact methods or heuristics. The thesis could also investigate other measurements that are not mentioned here, or approximations of the before mentioned measurements.

4. PREREQUISITES: Operations research methods, combinatorics, graph theory, programming skills (Java, C++, C#, Julia).

5. GROUP SIZE: 1-2 students

6. CHARACTERISTICS OF THE ASSIGNMENT: Developing algorithms for clustering and/or community/betweenness/centrality detection in social networks.

Scheduling Major Component Exchange At Offshore Wind Farms

1. SUPERVISOR: David Pisinger, Michael Berliner Pedersen (Ørsted), Simon Spoorendonk (Flowty)

2. PROJECT BACKGROUND: In the operation of offshore wind farms the exchange of major components like gear boxes or blades requires jack-up vessels. These are usually leased for a period of time to perform maintenance at one or multiple wind farms. The planning of the major exchange component tasks is done for 3-6 months at a time. The planning is affected by factors such as weather conditions, predicted turbine failures, and contractual terms of the jack-up vessels. The project is carried out in collaboration with Ørsted A/S and Flowty ApS. Ørsted is a global offshore wind farm operator. Flowty offers a library of algorithms tailored for network optimization.

3. PROJECT ASSIGNMENT: The purpose of the project is to use network optimization to schedule the maintenance tasks for the given time horizon. With offset in existing planning models a mathematical model must be built that captures aspects like the seasonal weather impact on task times and the stochasticity in the predicted turbine failures. A solution approach should be implemented, e.g., as i) a meta-heuristic or ii) a column generation algorithm (exact or math-heuristic).

4. PREREQUISITES: Programming skills (Julia, Python, C++), good knowledge of network optimization and concepts like column generation, dynamic programming.

5. GROUP SIZE: 1-2

6. CHARACTERISTICS OF THE ASSIGNMENT: exact methods, heuristics, framework

7. REMARKS: The exact same project is also offered with Stefan Røpke as DTU supervisor.