1 Introduction and Motivation

The network is the core component for air cargo airlines. It determines the market potential as well as the (operating) cost. Due to the air freight market dynamics the design of the network as well as the operational schedule has to be adapted constantly. Key questions on this tactical and strategic level are for instance

- What hubs should be operated?
- What is the optimal fleet size and mix?
- Which markets/which demand should be served?
- Which flights should be operated?
- What is the impact of demand/prize/cost changes?

To be able to analyze the impacts of potential network and schedule changes in this complex environment involved analytical tools based on complex mathematical models are mandatory.

In this talk we present a planning paradigm which is ideally suited for analyzing strategic options for network and schedule reconfiguration, we introduce a mathematical program and solution method that supports this approach, and, we present the results of a model-based simulation of network (re-)configuration /optimization at cargo airlines under different EU ETS scenarios.
2 The model based approach

We have developed a mathematical programming model, solution algorithm and decision support system that is able to support the analyst on these reconfiguration issues. The approach is based on a new “pragmatic planning paradigm” to air cargo network and schedule planning which aims at adapting existing networks and flight schedules. The approach differs from most other optimization approaches presented in the research literature as it does not plan on the level of single flight legs but on the level of predefined flights, i.e. sequences of flight legs. The mathematical program integrates three fundamental subproblems which are often solved sequentially:

1. Given a (fixed) set of flights, which may be either own (internal) flights or external flights from an aligned passenger airline or road feeder service, the planner has to assign an aircraft type to every internal flight (fleet assignment) and to create feasible rotations on the set of internal flights respecting operational requirements like maintenance feasibility etc. (aircraft routing problem). These problems together are modeled as network flow problem using a time-line representation and leads to a mixed integer programming problem.

2. Given a schedule created in Step 1, the (operational) cost of the network can be calculated. The resulting profit can be determined by optimally selecting and routing demand. This is modeled as a path based multi-commodity network flow problem.

Now the integrated model distinguishes between optional and mandatory flights and selects the optimal combination of flights within both classes.

The approach leads to a complex high dimensional mixed integer program for which we have developed a state-of-the-art branch and price and cut – procedure (BPC). Although BPC, i.e. the combination of branch and bound, column generation and cutting planes, is well understood and has been applied successfully to various complex planning problems in logistics and other areas the implementation of a BPC approach is by far not trivial or straightforward. Designing efficient and effective procedures for the different components as well controlling the interaction of the components requires experience, creativity and testing.

In our implementation we specifically focus our elaborations on cutting planes as well as the branching strategy, which both have a significant influence on the quality of the first and best integer solutions found. A specific type of cutting planes – implied bound cuts – proves
to be especially powerful as it tackles the problem of poor upper bounds obtained when solving the linear programming relaxations due to the fact that the fixed costs of optional cargo flights are not accurately represented.

3 Application – Does EU ETS instigate network reconfiguration?

From 2012 on aviation is included in the European Emissions Trading Scheme (EU ETS) and operators have to hold one allowance per ton of CO₂ emitted on every flight departing from and/or arriving at an airport within the EU. Now two questions are of interest: Is it profitable for airlines to reconfigure their routes to reduce EU-related emissions and costs, and, will the schema be successful in the sense that emissions are reduced significantly. Here the potential for and the consequences of reconfiguration are different for the passenger and cargo business: while passengers book complete itineraries i.e. sequences of legs from an origin to a destination, a cargo booking is generally just an origin-destination pair with a time constraint and hence the airline has some freedom to route goods from their origin to their destination.

In a simulation study we have examined the impact of different possible ETS-scenarios for a (single) airline and its options as an enterprise to adapt production by designing the network and routing cargo intelligently.

We show that our specific planning approach can be adapted straightforwardly to support air cargo scheduling and network design under the regulation of EU ETS that emission is free only up to a certain amount and any additional requirement has to be paid for. For that purpose we have extended the basic air cargo network model to also represent this specific EU ETS regulation. Then the effect and appropriateness of network redesign can be estimated in a simple what-if analysis by a comparison of the optimal schedule obtained by applying the basic model with the optimal schedule for the model including the EU ETS regulation.

To our knowledge this is the first study addressing the air cargo market and also it is the first study that uses an involved mathematical model capable of optimizing the entire network. With such a model the rather narrow relation-based analysis which has been discussed in earlier publications for the passenger sector is replaced by an analysis which is able to respect all network effects. And the consideration of these network effects is especially important in the cargo sector since they determine the options for adaptivity.