SINTEF

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The SINTEF group is a leading multi-disciplinary research organization (see www.sintef.no) Its department of Applied Mathematics optimization group is internationally renowned with world class expertise in the state-of-the-art exact and meta-heuristic search algorithms needed to provide fast robust solutions to scheduling, routing problems: For the past twenty-five years we have developed industrial strength optimization methods, software prototypes, libraries, and components for automated planning across a range of application areas. Our results have been commercialized through several channels, including a spin-off company, software houses, and to industrial and public end users. SINTEF is a member of the NATMIG consortium and participates in 32 different SESAR projects ranging from wake vortex simulation, remote tower and safety support tools to decision support tools for Air Traffic Control.

SINTEF ATC Optimization Library[1]

SINTEF ATC Optimization Library finds the best possible position, orientation, and speed for each mobile on or near the airport at each point in time. By doing this, it can build detailed trajectories from the stand (or from any location on the airport), via the runway, and to the TMA exit and vice versa. It does so optimally and with very fast response times (typically within 30 millis) by exploiting state-of-the-art mathematical optimization. The core of the library have been developed and refined for over 25 years by SINTEF for a variety of industries. SINTEF ATC Optimization Library is especially tailored for the particular needs of the Air Traffic Management industry. Its functionality have been verified and validated in several SESAR projects (SESAR 10.9.2, SESAR 12.3.2, and SESAR 12.3.3). Software partners and their customers have access to unique conflict-free routing, sequencing and scheduling algorithms through this library. SINTEF ATC Optimization Library gives Air Traffic Control the means to achieve smooth and efficient airport operations.

As a natural consequence of the ability to generate detailed trajectories, the library also can propose the most optimal combination of higher level decisions:

Routing decisions

- Stand manoeuvre to use (e.g. long pushback, short pushback, most suitable pushback point),
- Standard route to follow,
- Runway entry or exit for each flight,
- De-icing location to use,
- Standard Instrument Departure route

Timing decisions

- Target Start-up Approval Time,
- Off-Block Time,
- Runway entry time and/or take-off time,
- De-icing time

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Sequencing decisions

- Runway sequence,
- Pushback sequence,
- Pre-departure sequence.

The flexibility of the SINTEF interface allows any ATC decision support system to extract and visualize the needed information from the proposed trajectories such that the Air Traffic Controller is supported with the right information at the right time.

In the figure below, a part of detailed trajectory that is planned with the SINTEF ATC Optimization Library at the Arlanda airport in Stockholm is shown in SINTEF's demonstration tool.

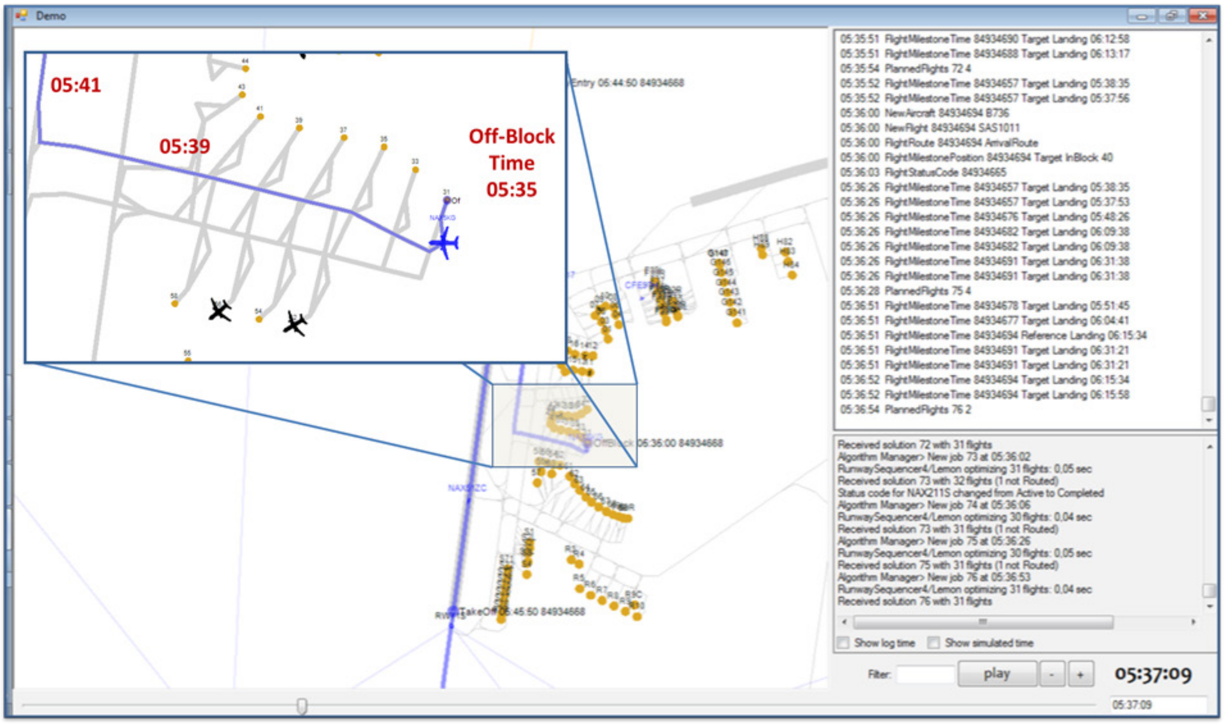

Figure 1: An optimal trajectory at Arlanda airport

Usage modes

The SINTEF ATC Optimization Library supports three different modes of usage:

- **Interactive or probing mode.** The Air Traffic Controller requests to calculate specific trajectories with his or her preferences and will receive then one or multiple trajectory proposals to consider for acceptance,
- **Automatic mode.** The library proposes automatically a new trajectory or a trajectory adjustment based on information it has received.
- **Combination of both.** Above usage modes can be used simultaneously.

Objectives

A combination of trajectories proposed by the library is called a solution. The library identifies among a very large number of possible solutions (see section Real-time Mathematical Optimization and Algorithms) the best possible solution based on a configurable set of criteria and their respective importance or in mathematical optimization terms: the objectives and their respective weights. Solutions with a better total value on an objective are considered better than other solutions and will be chosen before the other one.

The main objectives of the library are:

- Maximizing runway throughput,
- Maximizing punctuality,
- Minimizing taxi time.

In addition, it can also take into account softer preferences such as minimizing the overloading of the en-route controller at the TMA exit point. In both interactive and automatic modes, the ATC Optimization Library is able to re-optimize very fast and could suggest different trajectories only giving the Air Traffic Controller a very short amount of time to react. This would be undesirable. Therefore, a special stability objective is used such that the proposed trajectories only change when it is really needed, when it improves efficiency of the total airport and when the Air Traffic Controller can manage to communicate the new trajectories.

Constraints

SINTEF ATC Optimization Library will not propose solutions that go against the airport ground rules or would not be possible by an airport to do unless ATC overrides them. The library takes into account the following type of constraints or restrictions:

Single trajectory constraints

- Turning radius restrictions,
- Forbidden stand manoeuvres,
- Closed taxiway for all or specific types of aircrafts (e.g. max. WTC, max. Wingspan)
- One-way taxi ways,
- Mobiles only or airplanes only allowed,
- Traffic type restrictions (departure, arrival).

Multiple trajectory constraints

- **Conflict constraints**. The library determines trajectories that are not conflicting with each other. Around every airplane or mobile virtual areas are drawn. They can vary in size and shape depending on the speed, activity, physical characteristics (e.g. wingspan, length) of the airplane, and radar precision. These virtual areas are not allowed to overlap at any point in time. This functionality is used to provide smooth taxiway operations at the airport (see figure Conflict-free trajectories).
- **Runway separations constraints**. The library will never plan a sequence of arrival or departure flights on the runway that violates the minimum runway separation times (e.g. wake vortex).

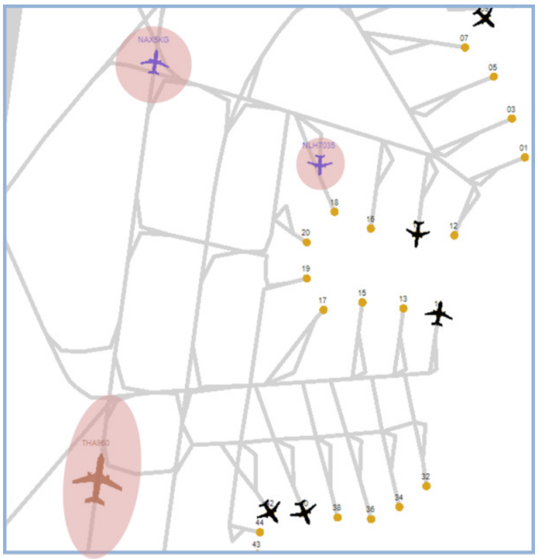

Figure 2: Conflict-free trajectories

Real-time Mathematical Optimization and Algorithms

In mathematical optimization, the problem faced by the decision maker is modelled by means of the mathematical formalism. Decisions to be taken are modelled by variables, whereas relations and constraints, as well as objectives, are represented as functions of the decision variables. This allows us to use the power of effective mathematical algorithms to find the best decision among a potential infinite number of alternatives. In ATC models, variables are typically associated with mobiles, aerodrome segments and times; a decision involves the selection of a sequence of segments (the route) for each mobile, and the times in which each mobile should move on the segments of its route. Constraints may regard temporal requirements, as well as the fact that the overall plan must be conflict-free. We could also consider various objectives, e.g. maximizing punctuality or minimizing taxi time (or a combination of the two).

In more detail, in mathematical optimization problem constraints and relations are represented by equations. The values of the decision variables satisfying all such equations are the feasible solutions. The objective can be any function, for example the sum of the values of the decision variables possibly adjusted with some weights. The optimization algorithm will determine, among a very large number of feasible solutions, the one with the largest possible objective function value.

The problem tackled by the Air Traffic Controller is what mathematicians classify as a hard combinatorial problem. It would be impossible for an ATC to evaluate all of the possible combinations of mobile routes, and all possible conflict-free schedules associated with such routes. So, even if in general skilled ATCs manage to find feasible routes and schedules, it is very unlikely that they can identify the optimal one.

For example, an ATC assigning to each of six distinct airplanes a route from a pre-defined set of six fixed routes would have to evaluate up to 720 combinations. Some of these combinations might violate some given constraints (e.g., maximum speed, crossing restricted area, etc.), while others would correspond to feasible plans. To find the optimal plan, all feasible combinations must be somehow evaluated against each other on properties the chosen objective (e.g., minimum overall delay, minimum taxi times, etc.). While six airplanes and six routes is a rather small problem (for computers), as these numbers grow, the number of potential combinations grows exponentially (see Table 1). And yet, a realistic ATC problem may be even more complex.

Table 1. Route assignment, a combinatorial problem

Number of airplanes	Number of routes	Number of combinations
6	6	720
12	12	479001600
25	25	15511210043330985984000000
50	50	3.0414093e+64

It is in this type of combinatorial problems that optimization algorithms excel over humans by implicitly searching through a very large number of combinations and quickly identifying efficient or optimal ones.