Applications and Experience in the Civil Aviation Sector

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Introduction

The civil aviation industry can be characterised as involving the *co-ordination*, *organisation*, *planning* and *scheduling* of high capital value, high operating cost, resources, within a highly organised and controlled environment. In particular, effective operation of air transportation systems involves the solution of ***n-dimensional placement***, ***planning*** and ***scheduling*** problems. Achieving the necessary levels of safety and customer service leads to many opportunities for developing and maintaining competitive advantage through the use of leading edge technologies.

Headway Systems Limited carries out projects within this sector using ***constraint solving technology***. Problem solving projects in this sector have addressed applications to ***runway holds modelling***, ***airspace capacity analysis*** and ***stand planning***. A review of these examples is followed by brief comment on the growing importance of the approach to problem solving typified by them.

Runway Holds Modelling

BAA plc, the UK based, world class airport operator

Detailed modelling of runway holding areas at London's Heathrow Airport was carried out for Heathrow Airport Ltd, a subsidiary of BAA plc, the world's largest independent airport operator.

The project work was directed by, and involved collaboration with, the Operational Research group (based at Gatwick Airport) of BAA plc. The requirements of the model were specified by BAA. The model was subsequently designed and constructed by Headway Systems using ILOG Solver/Schedule and C++.

BAA, responsible for all terminals and airfield operations, is continuously monitoring the service provided to passengers and airlines. Part of this process involves the modelling of airport activity, ranging from the analysis of waiting times at check in desks to considering how to ensure the prompt departure of aircraft.

The model of the runway holding areas, whilst still at an early stage in its development, has been used in a number of experiments to contribute to the medium and long term planning and operation of airfield resources.

It plans, in a modelling context, movements of aircraft 'objects' through the model of the runway holds, using data which represents, for example, expected taxiing times, available routes, line up time, time to airborne and airspace separation requirements.

Each aircraft was required to be airborne within a valid departure slot window, whilst satisfying airspace rules for route/speed, wake vortex separations, and Minimum Departure Intervals. Multiple line-up and resequencing of aircraft was used where possible to reduce delays at the holding area. A graphical representation of the output, representing a set of modelled aircraft movements, was used by the airport to verify that the model was working realistically.

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Airspace Capacity Analysis

National Air Traffic Services (NATS) of the UK Civil Aviation Authority

NATS has wide ranging responsibilities in relation to the management of UK airspace and air traffic control systems. An important part of its activities is focussed on ensuring that, in the medium and longer term, UK airspace and its control systems have appropriate capacity to cope with anticipated traffic demand.

Airspace capacity is a complex subject, involving, in different combinations, issues related to:

a) safety;
b) levels of available CNS (communications, navigation and surveillance) technologies;
c) traffic demand forecasts;
d) airport development;
e) aircraft design development;
f) the 'structure' and management of airspace itself.

The project carried out by Headway Systems for NATS is part of an ongoing programme of development of medium to long term strategies for airspace and air traffic management. The particular focus of Headway's project is to develop a method for analysing airspace structures and traffic patterns to enable comparative statements about traffic handling capacity.

At the centre of the conceptual basis of the approach taken by Headway's project is the assumption that airspace capacity is limited by the extent to which it is possible to control the flights (i.e. the trajectories) of all aircraft in a manner which respects the defined rules of the airspace management system. The heart of the approach is a model which generates schedules of aircraft trajectory modifiers, which, if applied to the aircraft concerned, would yield such a set of aircraft movements.

To evaluate strategic options in airspace management, NATS use a fast-time simulation model of traffic passing through airspace which is assumed to have no air traffic control. This approach permits evaluation of the airspace structures as opposed to the control regime. Close approaches (conflicts) between aircraft are registered when their space-time trajectories break pre-defined rules of minimum separation.

Analysing the outputs of the simulation, the constraint modelling technique partitions the overall problem into tractable sub-problems (defined in terms of a limited timespan and 3-D space). For each of these sub-problems, the model generates a set of trajectory modifiers which resolve any conflicts which are present. Combining the results provides an indication of the nature, frequency, and overall number of, control operators required in order to manage the airspace scenario.

Constraint programming is applied innovatively to the problem both in terms of the maintenance of minimum separations, and in relation to the allowable and desirable range of movement of individual aircraft.

The method is at a prototype stage both in terms of the software and the theoretical approach.

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Stand Planning Application

British Airways, the UK based, world class airline

British Airways, in common with other leading airlines, manages the operations of airport terminals at its home base (London's Heathrow Airport) and elsewhere. It is important for British Airways, in planning facilities and operations so as to enable the provision of the highest quality of service to passengers, to have tools that will support evaluations of the stand layouts and facilities of the terminals. These evaluations should enable the airline to determine the impact of changes to the schedule and operating assumptions.

Headway Systems has undertaken a project for British Airways to deliver a stand planning tool capable of evaluating the effect of different stand layouts on Customer Service. The system generates stand allocation schedules which satisfy user specified levels of customer service, which is defined in terms of the proportion of passengers provided with 'on pier' service.

Key requirements of the tool included the need to provide the ability to:
- check robustness of stand layout against different schedules;
- make quick changes to stand service and operating assumptions;
- model flexible stands;
- quickly produce reports giving details of solution.

At its simplest level, the stand planning application can be described as reading a list of **required aircraft movements** (i.e. arrivals and departures and the aircraft which are associated with each), and scheduling the allocation of airport stand resources (i.e. stands and parking locations) to meet the required movements, thus producing a **stand allocation plan**. The system must achieve a **service provision** schedule for the required arrivals and departures on-time without violating rules such as occupancy of stands, and without exceeding the available resources. In so doing it seeks to achieve a minimum **quality level** of the resulting stand allocation and then to **improve** this quality level. The quality level is a measure of the stand allocation plan in terms of customer service and operational metrics.

The movement list contains such information as the flight number, arrival and departure times and airport names, aircraft type, passenger numbers, etc.

Airport resources are represented as:
- parking lines which aircraft physically occupy;
- stands which handle passengers;
- stand blocks which represent physical adjacency of stands (sections of buildings or terminals).

These resources can have **time dependent behaviour** over the period of the stand allocation plan.

The starting point for the construction of any given plan can be either a set of unused stands, or any combination of stands previously committed to servicing flights. In other words the system supports **incremental stand scheduling**.

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Constraint Programming in Civil Aviation

The examples of applications developed using constraint programming technology which have been described in this and other papers provide a view of the breadth of the types of problem which can be addressed successfully.

Examples of applications include:

Aircraft stand planning and allocation	Maintenance planning (rosters, facilities etc.)
Airline fleet scheduling and movement planning	Catering management
Airline flight crew scheduling	Revenue management
Flight planning	Baggage belt allocation
Airline ground staff and equipment scheduling/rostering	Baggage and freight packing (configuration, loading/unloading etc.)

These application areas are characterised by being complex, combinatorial, time based and of a high value. All have characteristics which provide the opportunity for the application of constraint programming. The modelling techniques involved, and the effective and readily understandable representation of significant features of the problem as constraints between variables, provide the flexibility to address the problem specific differences found in airline business applications.

The use of constraint programming techniques, in conjunction with intelligent search, lowers the barriers to the solution of combinatorial problems of increasing degrees of complexity (particularly when compared to the achievable results using what may be termed conventional search based solutions). The increased complexity which can be addressed may be a reflection of, for example, an increase in the numbers of 'objects' being considered or an increase in the complexity of the objectives of the solution generation process.

For example, it becomes more feasible to consider building applications, within acceptable development time and costs, in which the complex trade offs between resource availability, service quality, time, and financial considerations can be modelled and managed during the generation of operational plans and schedules. The 'in built' power of constraint programming languages and libraries provide highly cost effective routes to the development of these types of applications, within the reach of any commercial organisation.

Some of the more recent developments in the technology of constraint programming have enabled such applications to be implemented using mainstream computing technology (e.g. C++) on a wider range (in terms of power, cost, and availability) of hardware/operating system environments (e.g. power PC with Windows) whilst retaining portability and facilitating integration with more conventional information technology such as GUI and DBMS.

Whilst it has only relatively recently been adopted for applications in the commercial world, constraint programming has become established as an important component in the solution of genuinely hard problems, and is providing real commercial benefits to those organisation which have taken it 'on board'.

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