

The Tactical Load Smoother for Multi-Sector Planning

Colin Meckiff¹, Renaud Chone and Jean-Pierre Nicolaon²

*Eurocontrol Experimental Centre
BP 91222, Bretigny-sur-Orge, France*

Abstract

The Program for Harmonised ATM Research in Eurocontrol (PHARE) has proposed a number of new concepts to address forecast problems of airspace capacity shortfall. One of these involves a redistribution of workload upward from single sector level, which currently represents a bottleneck in Air Traffic Control, to a wider multi-sector area. A specialist controller known as a multi-sector planner would work this new area.

This paper describes a tool, the Tactical Load Smoother, which is designed to support the multi-sector planning activity by providing functionality to analyse future traffic, and then produce a clear indication of when and where conditions are likely to become excessively difficult for sector-level controllers. Having identified potential problems, the controller may then intervene in some way to reduce or eliminate them in a timely fashion.

After a description of the PHARE context and operational scenario, this paper will undertake a technical discussion of the TLS, with descriptions of the algorithms and examples of the resulting displays. Some early results from the PD3 experiments will then be discussed, and finally, the paper will indicate directions for future research.

Introduction

The Program for Harmonised ATM Research in Eurocontrol (PHARE) has proposed a number of

new concepts to address forecast problems of airspace capacity shortfall. One of these involves a redistribution of workload upward from single sector level, which currently represents a bottleneck in Air Traffic Control, to a wider multi-sector area. The function of the newly created 'multi sector planner' would then be to survey the projected future traffic situation over a wide area, and identify any conditions, well in advance, which could give rise to excessively complex situations for the sector controllers. They would then intervene in some way to reduce or eliminate problems in a timely fashion.

When considering operations over several sectors there are two important issues. The first is that the number of aircraft to be handled at any moment could be substantial. If current forecasts are correct, with a doubling of aircraft numbers in approximately 15 years, then a multi-sector planner with responsibility for, say, four sectors could be expected to handle hundreds of aircraft per hour. Secondly, since multi-sector planning implies working over longer timescales, with transit times for the control area of up to, say, 40 minutes, the degree of uncertainty associated with predicted aircraft trajectories is correspondingly larger. Under these circumstances traditional controller skills of checking for future problems, by mental extrapolation based on flight plan information and surveillance data, become impracticable.

The Tactical Load Smoother (TLS) is a tool that was developed to support the multi-sector planner in his work. Its purpose is to analyse future traffic, taking into account a number of parameters including

¹ colin.meckiff@eurocontrol.fr

² jean-pierre.nicolaon@eurocontrol.fr

prediction uncertainty, and to produce an indication of when and where conditions are likely to become excessively difficult for sector-level controllers.

The simplest indicator produced by the TLS is a Traffic Load Graph, and is a display of aircraft numbers for times between 10 and 40 minutes into the future. Additional information is provided by breaking the graph down into climbing, descending and cruising aircraft. A second, slightly more complex indicator is known as a Problem Load Graph, which is calculated according to the number and degree of certainty of conflicts predicted to occur within the area. As with the Traffic Load Graph, it is displayed for 10-40 minutes into the future. On each of these graphs, thresholds indicate acceptable levels of traffic count or conflict count respectively.

The most sophisticated display, and the most important innovation of the TLS, is known as the Complexity Map. This shows, for a given time in the future, a set of 'complexity zones' that correspond to the calculated degree of complexity at each point in the multi-sector area. This can be imagined as a sort of 'heat contour map', with hotspots, indicating potential high complexity, shown in red. Areas giving rise to slightly less concern may then be shown in orange, and so on. In this way the controller can see not only the fact that there are expected to be difficulties somewhere, but he can also see exactly where they will occur. Interacting with the complexity map, the controller may zoom-in on the hotspots, to identify the contributing flights, and formulate a resolution strategy.

Whereas the Traffic and Problem Load Graphs are levels plotted against future time, the Complexity Map is calculated for a single moment in the future, and is projected onto a standard plan view display for the sectors concerned. The future time for this display is selectable by the multi-sector planner, and will often be chosen as a point on the time axis of either the Traffic or Problem Load Graphs (with a mouse click) corresponding to an indication of excessive load on either or both of these.

The zones in the Complexity Map are calculated according to a number of parameters, including: the probability and nature of conflicts between two or more aircraft; the equipment levels of the aircraft (3D FMS, 4D FMS, datalink etc.); the aircraft's speed; the aircraft's vertical evolution (climbing, descending or stable); the aircraft's sector transit time; compatibility between an aircraft's route and

it's flight level; the distance of the problem from the boundary of the sector. These elements are combined according to a set of rules and weightings which have been derived both analytically, and empirically using input from experienced air traffic controllers.

The Tactical Load Smoother was an important part of PHARE Demonstration 3 (PD3) which ran in May 1998.

After a brief description of the PHARE and PD3 contexts and operational scenarios and a discussion of multi-sector planning concepts, this paper will give a technical presentation of the TLS, with descriptions of the algorithms and examples of the resulting displays. The paper will then give some early results from the PD3 experiments. Although technical difficulties and limitations meant that no formal measures were taken during PD3, results based on controller feedback are proving useful. Finally, the paper will give a realistic assessment of the potential of the techniques in real-world situations, together with directions for future research.

PHARE and the PD3 demonstration

The Program for Harmonised ATM Research in Eurocontrol (PHARE) is a co-operative effort between European research establishments³. It was created to co-ordinate and conduct studies and experiments to demonstrate the feasibility and benefits of a future air-ground integrated air traffic management system in all phases of flight. The results of the programme, which was initiated in 1989, are being fed into descriptions of future air traffic system concepts, and in particular are helping to provide information on the best way to transition from the current to the new system.

PHARE scenarios

An important start to the PHARE work was the definition of the PHARE medium-term scenario for years 2000-2015 [Ref. 1]. It fixed options and made more concrete assumptions than had been the case for previous comparable documents. This initial

³ The co-operating PHARE research establishments are:

National Air Traffic Services (UK), Centre d'Etudes de la Navigation Aérienne (France), Deutsche Forschungsanstalt für Luft und Raumfahrt (Germany), Nationaal

Lucht-en Ruimtevaartlaboratorium (Netherlands) and the Eurocontrol Experimental Centre.

scenario was subsequently complemented by more detailed operational scenarios for the PHARE Demonstrations [Refs. 2, 3, 4].

Elements of the PHARE program

Demonstrations

Three PHARE demonstrations (PD's) have been executed. They comprised large-scale validation activities with integrated ground systems, air systems and air-ground datalink facilities. Demonstration work comprised preparation of the ground and air sites (trials and simulated aircraft) and the integration of the advanced tools.

PHARE Demonstration 1 (PD1) [Ref. 5] was run in 1995 and concentrated on en-route issues, simulating several sectors and entry/exit conditions at TMA boundaries. PD1 was hosted by DERA⁴ at Malvern, UK.

PHARE Demonstration 2 (PD2) [Ref. 6] was run in 1996 and addressed terminal approach issues by simulating several sectors of an extended TMA and emulating entry and exit conditions at en-route sectors. PD2 was hosted by DLR at Braunschweig, Germany.

PHARE Demonstration 3 (PD3) addressed multi-sector, en-route and extended TMA issues. A more detailed description of PD3 is relevant to this paper, so is given in a separate section below.

Tools and Functions

New tools and functions were required to enhance the experimental facilities of participating PHARE partners in order to run the demonstrations. Such developments included the following:

- PHARE Advanced Tools - to provide a number of ground-based controller support functions appropriate to the new operational requirements.
- Ground Human Machine Interface - prototyped and developed a common man-machine interface appropriate to the new functionalities.
- PHARE Aeronautical Telecommunication Network - an experimental ATN to support air-ground and ground-ground communication.
- Experimental Flight Management System - to support 4D flight management, air-ground data communication and ATC constraint processing. Also included an Airborne HMI.

⁴ Defence Evaluation and Research Agency

- Meteorological model - an experimental short-term forecasting model to improve trajectory prediction.
- Validation tools - to support analysis of the various evaluation exercises.
- Common Modular Simulator - a common simulation environment with standard software interfaces based on a client-server approach.

More about PD3

PHARE Demonstration 3 was run on three separate sites (EEC, Bretigny; NLR, Amsterdam; and CENA, Athis Mons) during the course of 1998. Each participating site studied a different aspect of the ATC problem, including en-route control, Extended TMA control and the integration of en-route and ETMA concepts.

The general aims of the EEC PD/3 experiments were to demonstrate a future air/ground integrated system in all phases of flight. More specifically, they were required to demonstrate the potential for capacity and productivity improvements within a full 'gate-to-gate' environment arising from:

- the use of layered planning techniques⁵ and multi-sector planning, to operate on traffic on a scale larger than the traditional sector;
- the introduction of advanced PHARE tools and associated GHMI to assist the controller in the organisation and planning of traffic;
- the introduction of specific Arrival and Departure Management tools;
- the introduction of 4D trajectory negotiation and editing.

The series of experiments conducted at the EEC during the month of May 1998 unfortunately did not achieve all the planned objectives due to technical limitations in the simulation platform. However for

⁵ PD3 defined complementary roles for different types of controllers with different time horizons for their respective activities. Thus the MSP was responsible for organising traffic between 10 and 30 minutes ahead; the planning controller worked up to 10 minutes before aircraft entered a sector to either solve conflicts (4D a/c) or prepare solutions (3D a/c); and the tactical controller implemented solutions prepared by the planner, assured real-time problem solving and handled radio communications. This type of organisation was generally known as 'layered planning'.

the purpose of this paper several important benefits are derived:

- a detailed study of the issues raised by multi-sector planning was undertaken;
- support tools for multi-sector planning functions were developed and integrated;
- there was useful feedback (principally verbal) from controllers who participated in the trials, and from preceding concept proving exercises.

The concept of multi-sector planning

The principle cause of air traffic delays in Europe today is limited runway capacity. A secondary cause is restriction in en-route capacity. In fact en-route restrictions are already the cause of many delays, and any freeing up of additional runway capacity immediately increases pressure on the sectors. En-route restrictions may occur in real-time (e.g. by stacking) or at the level of flow management (e.g. by metering or in-trail spacing), and are imposed to allow controllers to handle their traffic in a safe and orderly manner. If numbers of aircraft increase above certain levels, this could lead to situations which are complex to the point of presenting difficulties which are beyond the competencies of controllers to handle safely.

The focus of concern here is the sector controller, and it is reasonable to assume that if some of his workload could be diverted elsewhere, then this would increase the number of aircraft he could handle and/or increase the level of safety of his operations. One way of doing this has traditionally been to allocate one or more assistants in support, which in some places has resulted in up to 5 people working a single sector. As with the practice of subdividing sectors, however, this is subject to rapidly diminishing returns as well as being expensive in staffing costs.

The assumed evolution in the quality of trajectory prediction provides other possibilities. If we are able to predict aircraft trajectories to a satisfactory level of accuracy over, say, 30 or 40 minutes, then we have the possibility of operating on traffic before it reaches the sector controller, with the objective of simplifying or resolving problems before they occur at that level. This would then reduce workload and consequently increase sector capacity.

The use of longer look-ahead times implies that control may span several of today's sectors (hence multi-sector planning). There are several possible

applications of this, and the following paragraphs outline some of those that were developed for PD3.

Assessing and monitoring the predicted traffic situation over a large area in order to develop an understanding of potential sector workload, traffic density, complexity of traffic flows and different types of traffic situation. The multi-sector planner (MSP) can use this understanding to develop strategic plans to reduce sector traffic complexity, balance traffic flows between sectors and optimise aircraft trajectories.

Reducing traffic complexity to reduce or simplify the actions that will have to be performed by sector-level controllers. It is achieved by manipulating trajectories to:

- simplify traffic flow to permit easier conflict analysis and provide greater room for manoeuvre;
- allocate temporary flight levels to avoid crossing problems;
- minimise disruption to arrival traffic profiles;
- resolve predicted conflicts.

Control methods to achieve the above include route offsetting, re-routing, planned descent, intermediate flight levels, and planned climbs.

Balancing traffic flows between sectors in conjunction with the reduction of traffic complexity. The MSP can smooth demand by redistributing traffic between sectors when an imbalance is apparent, possibly as a result of a sector workload threshold being exceeded. Different techniques may be used dependent on whether sectors are superposed or adjacent.

Optimising aircraft trajectories through provision of direct routings and preferred levels based on flight plan or pilot request. Optimising an aircraft's trajectory may use a combination of parallel/off-set tracks, direct routes and early allocation of requested levels.

Co-ordination and clearances. The greatest challenge of any multi-sector planning application is the definition of the role of the MSP relative to that of his sector-level colleagues. In other words, if the MSP proposes to intervene in some way, what are the rules for transmission of new clearances and how are they co-ordinated between all the levels involved? What are the rules for prioritisation and pre-emption? A discussion of these complex aspects is outside the scope of this paper, but it constituted a major part of the development of the concept for the

PD3 simulation. The result was a complicated mixture of rules for automatic co-ordination and clearance transmission in some cases, and manual processes in others. [Ref. 4]

Description of the Tactical Load Smoother

When considering operations over several sectors two important issues must be taken into account. The first is that the number of aircraft to be handled at any moment could be substantial. With a doubling of aircraft numbers forecast in approximately 15 years, a multi-sector planner with responsibility for three or four sectors may be expected to handle hundreds of aircraft per hour. Also, since multi-sector planning implies working up to 40 minutes ahead, the degree of uncertainty associated with predicted aircraft trajectories is significant, even with the latest prediction technologies. Under these circumstances traditional controller skills of problem analysis by mental extrapolation become impracticable. The TLS is designed to support a level of analysis of multi-sector traffic that would otherwise be beyond the capabilities of a human controller.

A key notion in the TLS is that of *complexity*, which may be arbitrarily defined as a measure of the difficulty that a particular traffic situation will present to an air traffic controller. The notion of *workload* for air traffic controllers has always been difficult to define, but it is clearly related to complexity in some way. In general terms we have assumed workload to be a function of three elements: firstly the geometrical nature of the air traffic; secondly the operational procedures and practices used to handle the traffic, and thirdly the characteristics and behaviour of individual controllers (experience, orderliness etc). Whereas traffic patterns may be defined in essentially mathematical terms, working practices, and particularly individual controller characteristics become difficult or impossible to formalise.

The TLS therefore makes no attempt to evaluate 'workload' as such. Instead, it has its own notion of complexity as defined above, based on mathematical algorithms together with elements of operational procedure and practice derived from controller knowledge. For the former it is possible to model aspects such as probability of conflict, using predicted 4D trajectories and their uncertainties. For the latter, controller knowledge was elicited to estimate, for example, the relative difficulty of

handling different types of conflict. The formulation is thus part mathematical and part heuristic.

Algorithms

It is assumed that the future path of each aircraft is characterised by a predicted trajectory of 4D points, sufficiently close to allow interpolation without significant loss of accuracy. For a given moment in time each point has an associated 3D zone of uncertainty. The basic dimensions of this zone for the TLS are defined by the size of the PHARE contract tube⁶. This is thought to be sufficient for the lateral and vertical dimensions, but not for the longitudinal dimension. In this case the uncertainty will be greater due to the longer look-ahead time of the TLS, and in particular the fact that a significant number of aircraft may not even have left the ground. Since in PHARE the predicted trajectory is calculated relative to take-off time, it is necessary to add uncertainties in departure time for those aircraft that are still on the ground. For aircraft in the air, uncertainty is added to allow for interventions prior to arrival in the multi-sector area e.g. there may be optimisation or avoidance manoeuvres by preceding multi-sector planners. The longitudinal uncertainties may differ ahead and behind, and are calculated as a function of time to take-off, time to entry into multi-sector area, and level of FMS equipment (on the basis that a 4D-equipped aircraft may be able to compensate for time discrepancies).

The TLS thus defines a modified version of the PHARE contract tube, with an extended longitudinal window due to the long look-ahead times involved (Figure 1).

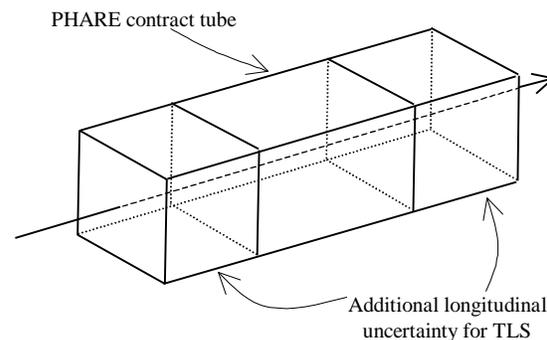


Figure 1. Augmented tube of aircraft presence for TLS

⁶ PHARE defines a *tube* as a series of 4D windows that are used to describe airspace volumes around a trajectory. More specifically, a *contract tube* defines the 4D airspace in which the aircraft has agreed (or contracted) to remain.

Probability of presence

To remain within the PHARE philosophy, it is assumed that the aircraft will *always* be present somewhere within the block of airspace shown in Figure 1 at a given time. This is reasonable since deviations from the tube are assumed to trigger a replanning activity, resulting in a new trajectory and tube. The predicted trajectory is supposed to represent the ideal according to the best available information about aircraft performance, meteorological conditions etc. It is thus assumed that the aircraft is most likely to be near its predicted trajectory at any moment, with a decreasing probability that it will be found towards the outer edges of the tube. To formalise this, a Normal Distribution is superimposed on each dimension of the tube, with the edges of the tube representing a certain number of standard deviations from the trajectory. It should be noted that:

1. The tube may be asymmetrical about the trajectory. This will often be true in the case of longitudinal error, where delay is more likely than advance, and also for turning manoeuvres. When superimposing the distribution it is possible to model this asymmetry in several ways e.g. by displacing the mean, or preferably by using some skewed distribution. For the purposes of this work it has been easier to assume a non-continuous Normal Distribution with 50% probability of presence either side of the mean. This implies a discontinuity at the mean, but for the purposes of this formulation this is not significant.
2. It has been an important part of this work to maintain generality in order to allow changes in the formulations as the prototype was being developed. Experimentation with different values, different types of distribution etc. has been, and will continue to be indispensable in the development of the TLS. For example, the distribution can be easily changed, and in practice would be chosen according to empirical results based on actual trajectory predictor performance and aircraft behaviour.

We can define, for a moment in time, t , the probability that an aircraft will be found in a particular volume of airspace from:

$$p_t = \iiint_{\text{volume}} D_t(\Delta lat, \Delta long, \Delta vert) \cdot d\Delta lat \cdot d\Delta long \cdot d\Delta vert$$

$$D_t(\Delta lat, \Delta long, \Delta vert) =$$

$$f_{\text{rightleft}}(\Delta lat) \times f_{\text{top,bottom}}(\Delta vert) \times f_{\text{aheadbehind}}(\Delta long)$$

Where:

? lat is the lateral distance between the point and its orthogonal projection onto the trajectory;

? $vert$ is the vertical distance between the point and its orthogonal projection onto the trajectory;

? $long$ is the difference between the reference time t and the time corresponding to the point along the trajectory.

And $f_{a,b}(x)$ defined by:

$$f_{a,b}(x) = K \times \frac{e^{-\frac{x^2}{2s_{a,b}^2}}}{\sqrt{2\pi s_{a,b}^2}}$$

$$K = \left[\int_{-k}^k \frac{e^{-\frac{x^2}{2}}}{\sqrt{2\pi}} dx \right]^{-1}$$

which is simply the Normal Distribution multiplied by a coefficient K which compensates for the fact that the function is truncated at the tube. k is the number of standard deviations to the edge of the tube. In practice a value of 3 is chosen for k (i.e. the tube is assumed to cover $\pm 3s$), which makes this coefficient near unity, but this may not always be the case.

In practice the size of *volume* is a compromise between accuracy and computation time. Small volumes will provide better granularity and accuracy, but will require more computation time and vice-versa.

Airspace occupation

The result of the above calculations is a set of values that give potential presence of a particular aircraft in a series of elemental pieces of airspace at a given time. This then needs to be mapped onto some arbitrary airspace structure to build up a global picture of occupation for all aircraft. To do this, the airspace is divided into cubes of an appropriate size, and the probability that a particular aircraft occupies each airspace cube is calculated. Since a conflict is defined as a loss of separation between a pair of aircraft, it is necessary at this stage to take separation

criteria into account. Thus if an elementary volume plus the separation volume intersects one of the predefined airspace cubes, then the probability that the aircraft will ‘occupy’ that cube is augmented by the value calculated for the element (Figure 2).

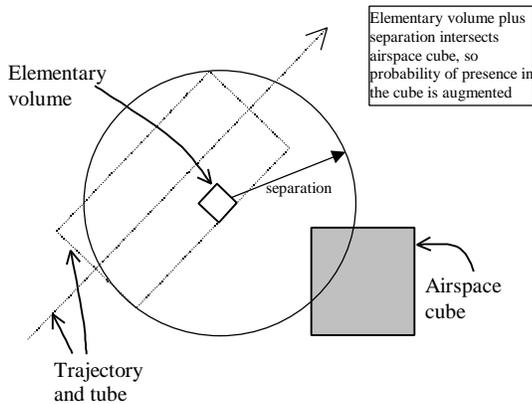


Figure 2 – Airspace Occupation

Density and complexity calculations

The values for airspace occupation give the basic information required to develop three quantities: traffic density, conflict density and complexity.

Traffic density is calculated as the sum of expectations of the presence of individual aircraft in a particular airspace cube.

Conflict density is calculated as the expectation of the simultaneous presence of any pair of aircraft in a particular airspace cube.

The complexity calculation augments the basic information with a number of new elements related to the position of the airspace cube within the sector, characteristics of each aircraft on its own, the aircraft relative to its situation within the sector, and each aircraft relative to other aircraft. Each of these is described in the following sections.

Airspace cube position in the sector

Complexity may be affected by the position of an airspace cube in a sector. E.g. intervention in the case of an aircraft that is near the edge of a sector may have restricted scope, and may imply additional co-ordination workload, hence will normally increase workload. Thus a complexity factor due to position within the sector, S(), is defined as

$$S(\text{Sector}) = \left\{ \begin{array}{l} in_centre \\ close_to_edge \\ very_close_to_edge \end{array} \right\}$$

And intuitively:

$$in_centre \leq close_to_edge \leq very_close_to_edge$$

Where the relationship \leq implies that a lesser degree of complexity results from the situation.

Attitude of an individual aircraft

Complexity will be affected by the individual characteristics of an aircraft. E.g. an aircraft which is fitted with a 4D FMS may be easier to manipulate than one which is less well equipped. A complexity factor due to the individual aircraft’s characteristics, A(), is defined as:

$$A(\text{Aircraft}) = \left\{ \begin{array}{l} 4d_fms \\ 3d_fms \\ no_fms \end{array} \right\} \times \left\{ \begin{array}{l} steady \\ climbing \\ descending \end{array} \right\} \times \left\{ \begin{array}{l} slow \\ medium \\ fast \end{array} \right\}$$

Intuitively:

$$4d_fms \leq 3d_fms \leq no_fms;$$

$$steady \leq climbing;$$

$$steady \leq descending;$$

$$slow \leq medium \leq fast.$$

Situation of an aircraft relative to a sector

The situation of an aircraft relative to its passage through a sector is a significant factor. E.g. if the track of the aircraft means that it crosses the sector in a short time, this limits the scope of possible manoeuvres. A factor due to the relationship between aircraft and sector, AS() is defined as:

$$AS(\text{Aircraft}, \text{Sector}) = \left\{ \begin{array}{l} correct_level \\ incorrect_level \end{array} \right\} \times \left\{ \begin{array}{l} long_crossing \\ average_crossing \\ short_crossing \end{array} \right\}$$

Intuitively:

$$correct_level \leq incorrect_level;$$

$$long_crossing \leq average_crossing \leq short_crossing.$$

Relationship between a pair of aircraft

Finally, the relationship between pairs of aircraft has an influence on complexity. E.g. if a pair of aircraft is in-trail, this could allow a greater number of manoeuvre options with greater time to act than if they are head-on. A factor due to the relationship between pairs of aircraft, AA(), is defined as:

$$AA(Aircraft_1, Aircraft_2) = \left\{ \begin{array}{l} both_level \\ both_climbing \\ both_descending \\ steady_and_climbing \\ steady_and_descending \\ climbing_and_descending \end{array} \right\} \times \left\{ \begin{array}{l} in_trail \\ crossing \\ head_on \end{array} \right\}$$

And intuitively:

$$\begin{aligned} in_trail &\leq crossing \leq head_on; \\ both_steady &\leq both_climbing/descending \leq \\ &steady_and_climbing/descending \leq \\ &climbing_and_descending. \end{aligned}$$

Overall complexity

Having defined the above functions, the global complexity can be calculated as:

$$\begin{aligned} Complexity &= S(Sector) \times \prod_{i=1}^n A(Aircraft_i) \\ &\times \prod_{i=1}^n AS(Aircraft_i, Sector) \\ &\times \prod_{i=1}^n \prod_{j>1}^n AA(Aircraft_i, Aircraft_j) \end{aligned}$$

Notes on the complexity formulation

Each of the values in the complexity formulation is a constant identified after interviews with controllers.

For computational purposes

- all constants are greater than or equal to unity,
- the values of *in_centre*, *4d_fms*, *steady*, *slow*, *correct_level* and *long_crossing* are set to unity.

Values for the remaining constants were set using constraints based on an ordering of a typical set of situations. For example, for the PD3 simulation, an

increasing order of complexity was defined for a single aircraft; a simple two-aircraft conflict; a complex two-aircraft conflict; multiple aircraft situations. Actual values were fixed with the help of a solver with all the above-defined constraints as input.

Displays

Sector Load Window

The traffic density and conflict density calculations are used in a display known as the Sector Load Window (Figure 3). In PD3 one of these windows was available for each sector in the MSP area.

Each graph is plotted against time, between 10 and 40 minutes into the future. The upper graph represents traffic load, with the number of aircraft on the Y-axis. As well as showing the overall count, the graph is broken down into the number of cruising, climbing and descending aircraft. The horizontal line shows the declared sector capacity (in this case 20 aircraft).

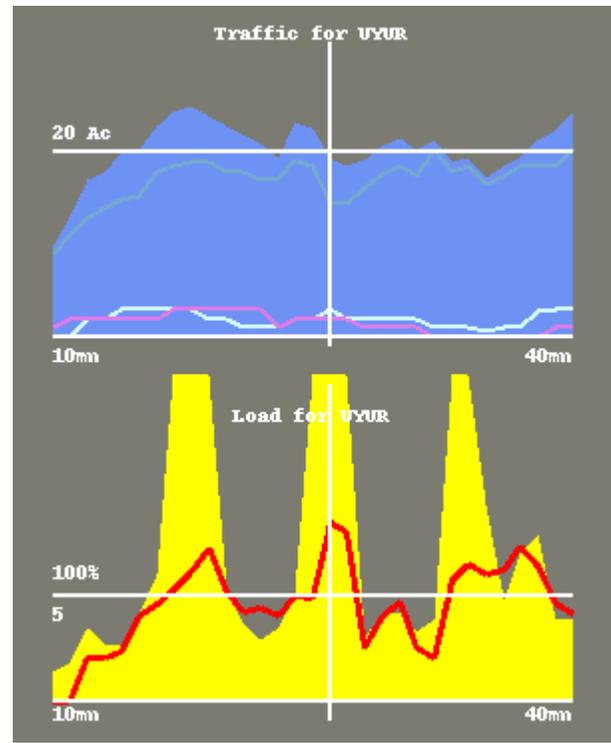


Figure 3 - Sector Load Window

The lower half of the window includes two graphs. The darker (red) line is a plot of the anticipated number of conflicts, and the lighter area is a plot of global complexity in the sector. A reference

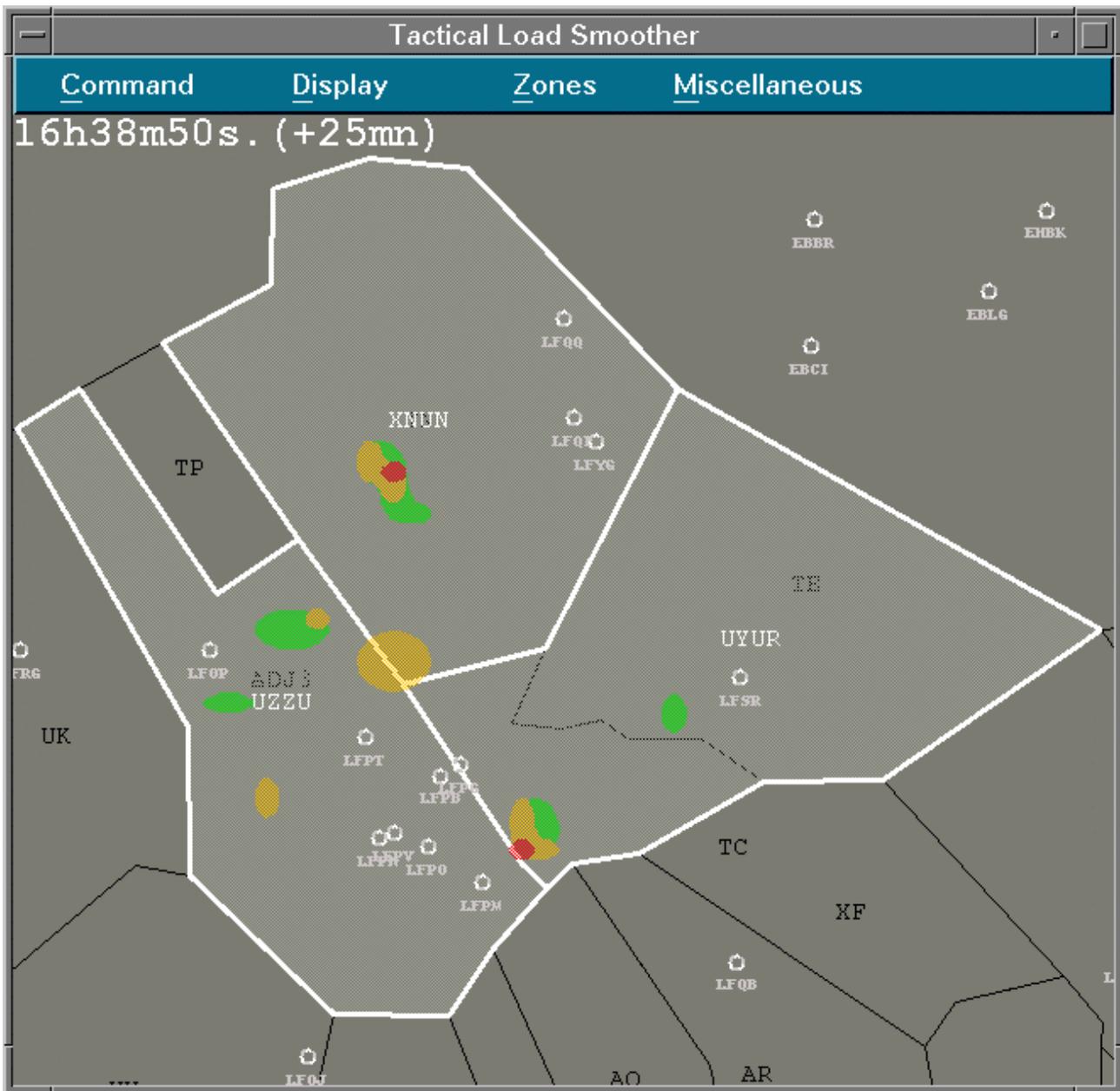


Figure 4 – Complexity Map

complexity is also shown as a horizontal line, and this will normally represent an upper limit of acceptability under prevailing conditions.

These graphs give the multi-sector planner an overview of what to expect in the future, and in particular will tell him when situations of over-complexity may occur.

Complexity Map

Whereas the Sector Load Window gives a view of the evolution of the global state of a sector over a time period, the Complexity Map localises areas of

potential complexity for a specific instant in time. A sample display is shown in Figure 4 (the pictures should be viewed in colour or electronically). It is a plan view that is constructed by projecting all the complexity values for a given column of airspace cubes onto a horizontal plane. The colour assigned to each part of the map is then dictated by the maximum (worst case) complexity value over the vertical column.

In practice the result of this process is a set of squares coloured in red, orange, green etc. For purely aesthetic reasons these squares are ‘rounded’ using a

Bezier function to give results of the type shown in Figure 4. In practice the rounding process does not appear to reduce the quality of the information, and indeed seems to make it more acceptable to controllers.

Use of the TLS in PD3

The TLS was designed for PD3 to support a number of multi-sector planning functions such as those identified earlier in this paper. In practice the multi-sector planner used the Sector Load Windows as his point of entry to the TLS. These gave a general overview of the status of sectors under his control in terms of potential loading and complexity. If the Sector Load Windows indicated high loading or complexity at a given time in the future, then the MSP was expected to investigate the situation in more detail.

To do this, he simply clicked on one of the sector

load graphs at a position equivalent in time to the moment when the problem was forecast to occur (this can be seen as a vertical white line in Figure 3). This called up the Complexity Map, which gave an indication of the locality and severity of the potential problem(s) for the chosen time. Working in the Complexity Map, the multi-sector planner was then able to display various types of information. One of the most useful features was the ability to zoom in on the complexity zones, allowing identification of aircraft that are expected to contribute to the problem. An example of this is shown in Figure 5, which shows a zoomed problem area, and the three aircraft that are expected to contribute to it.

It is also possible in PD3 to perform a small simulation on this zoomed map, advancing and retarding traffic by a few minutes to allow full evaluation of the situation.

Having fully understood the nature of the problem,

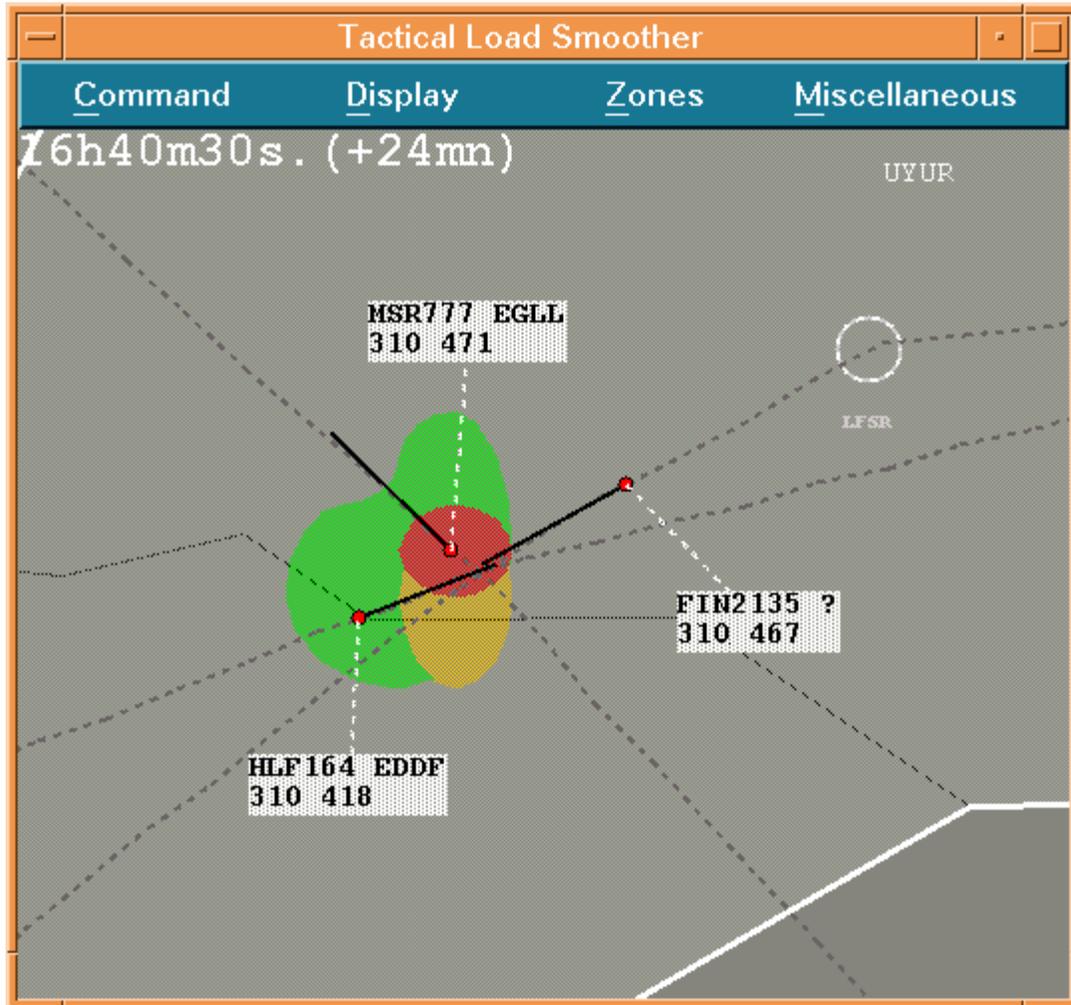


Figure 5 – Zoomed Complexity Map

the multi-sector planner was expected to use his experience to decide whether or not to intervene in some way to simplify the situation, and in PD3 he could do this using a trajectory editing capability.

Using these procedures it can be seen that the controller is spared having to analyse potentially large amounts of 'raw' data (hundreds of aircraft), and can move rapidly to a situation where he is in a position to address specific problems and modify traffic patterns. It should also be noted that when it comes to acting on this information, the TLS does not usurp the skill and experience of the controller, who is still expected to examine the predicted traffic situation and react (or not) as he sees fit.

Results

The TLS was evaluated in two stages. First, it was tested as a small-scale prototype (known as an IOCP – Internal Operational Clarification Project) in preparation for PD3, and then as part of the PD3 simulation itself. Whereas the IOCP experiments were conducted to a satisfactory level [Ref. 7], the PD3 simulation was not executed in its entirety, with the consequence that its results were not of a quality to be able to draw clear conclusions. Nevertheless, the two experiments did give a number of useful indications:

- The concept of layered working (successive levels of control) was judged worthy of significant further investigation. Layered working includes multi-sector planning as a key element.
- A representation of anticipated traffic situations such as that provided by the TLS for PD3, to allow the multi-sector planner to study future traffic in detail, was essential.
- The TLS did allow the multi-sector planner first to identify key problems which are likely to overload sector controllers, and secondly, to organise his priorities according to the forecast complexity for each sector.

Discussion with controllers revealed further suggestions for future developments of the tool. With regard to the complexity zones it was requested that they be reworked to reduce the relative significance of pure conflict probability in the calculations, rather to take a broader view of what constitutes a 'problem' situation. This should lead to smaller zones being combined to make larger ones, indicating a greater number of aircraft per 'problem'

(but probably fewer problems). This would be more compatible with the way controllers currently analyse situations.

It was also recommended to develop a means of indicating which aircraft contribute the most to particular complexity zones. In many cases the removal of a single 'troublesome' aircraft could significantly simplify what appears to be a quite difficult problem.

Since the notion of traffic flow is important, it was further suggested that a display be developed to indicate the distribution and behaviour of flow patterns in the multi-sector airspace.

Finally, it was proposed that tools be developed for manipulating several trajectories in one simple action, using some sort of 'macro' system. This would be an improvement on the existing simplistic trajectory editing capabilities available to the MSP, and would support both flow balancing and complexity reduction.

Conclusions

This paper has described a new controller tool known as the Tactical Load Smoother. This tool provides support to multi-sector planning activities by analysing traffic over a large area, and displaying forecasts for loading and complexity. A key output is the Complexity Map, which allows localisation, in space and time, of traffic situations that are potential sources of difficulty for sector-level controllers.

In view of the interest generated by the work so far, it is appropriate to continue studies and further validate the concepts and tools up to a pre-operational level. It will be particularly important to further develop the algorithms and operational concepts, and to this end flexibility in the TLS formulations has been an important part of the development process.

The TLS was developed with the objective of satisfying a future operational context (PHARE), which assumed tight ground-air coupling and a proportion of aircraft equipped with 4D-FMS capability. It is, however, envisaged that the TLS could be adapted for nearer-term operations using current trajectory prediction technologies and CPDLC rather than the more exotic PHARE proposals. In this case the functions performed by the TLS would be similar to those developed for PD3, complemented by a more formal definition of

the respective roles of multi-sector planning, sector planning and tactical control.

A project to undertake this work is in the process of elaboration by Eurocontrol. It differs from the preceding PHARE work in the technological assumptions, and especially in the fact that it will examine, in detail, how to progressively transit from current ATC working methods to those that will be required when new tools are implemented.

References

[1] PHARE Medium Term Scenario, 2000 to 2015. Issue 1. July 1990.

[2] PD1 Operational Scenarios. PHARE Document 94-70-28.

[3] PD2 Operational Scenarios. PHARE Document 95-70-11.

[4] PD3 Operational Scenarios. PHARE Document 97-70-04 and 97-70-08 (2 Volumes).

[5] PD1 Final Report. PHARE Document 96-70-24.

[6] PD2 Final Report. PHARE Document 97-70-13.

[7] IOCP En-route Multi-Sector Planning Procedures. PHARE Document EEC/PD3-2.1/REP_01;1

Note: most documents available from www.eurocontrol.fr.